NUCLEAR ENGINEERING VOL. 3 NO. 22 JANUARY, 1958

Reorganizing the C.E.A.

THE Central Electricity Generating Board announces that upon the reorganization of the electricity supply industry on January 1 in consequence of the Electricity Act, 1957, it proposes to devolve more responsibility, autonomy and power on the provincial establishments. The existing Generating Divisions will continue as operational management units and they will be grouped under Regional Directors as follows: (1) North Eastern and Yorkshire, (2) Midlands, and East Midlands, (3) Eastern, London, and South Eastern, (4) Southern, South Western, and South Wales, (5) North West, Merseyside and North Wales.

The existing technical organizations will remain under the Divisional Controllers, but accountancy and some administrative functions will gradually be brought together at the Regional Offices. Each region will have a Regional Executive Committee which will administer the region within the broad policy rulings laid down by the Central Board.

The development of the industry is such as to make it impossible to secure a uniform load on the construction staffs of the eleven Divisions, or even the five proposed regions; it is therefore planned to establish three separate "Engineering Project Offices" as follows: (1) North (possibly at Leeds or Manchester) working for the North West, Merseyside and North Wales, North Eastern and Yorkshire areas, (2) Midlands (possibly at Birmingham or Nottingham) working for the Midlands, East Midlands and South Wales areas, (3) London, working for the London, Eastern, South Eastern, Southern and South Western areas.

The project offices will have flexible boundaries to enable them, when convenient, to undertake projects in adjoining areas. They will undertake construction of new stations or major extensions to existing stations and construction of the associated switching stations, and will deal with nuclear as well as conventional power stations.

At the same time the Electricity Council states that since it has an overall responsibility for research in the industry, the Research Laboratory buildings at Leatherhead, Surrey, will vest in the Council, i.e. the property belongs to the Council. At the moment more than 80% of the work at Leatherhead concerns the generation and transmission side of the industry, and it has, therefore, been agreed that the contracts of service of the staff at Leatherhead will vest in the Generating Board, pending further consideration of the type of research to be carried out by the Council and Generating Board respectively.

These moves are in accord with the recommendations of the Herbert Committee which called for an organization in which responsibility for the generation of electricity and supply in bulk should be divorced from the general responsibility for the entire industry. With increasing size of stations the necessity for co-ordinating divisional building effort increases, and the three project offices are likely to be handling nuclear stations of a capacity of over 500 MW as a normal practice in a very few years' time.

What is not apparent yet, is the technical backing on the nuclear side that the project offices will have or to what extent the research laboratory proposes to extend its facilities to cater for nuclear generation. The Atomic Energy Authority, for the next seven years at least, will act as a consulting organization with very considerable powers, but to what degree the C.E.G.B. proposes to become independent in this respect remains to be seen. With the three stations now in hand, quite a considerable body of experience is being built up, but much more than this is required if the Generating Board is to develop a staff able to assess in a comprehensive manner, commercial tenders.

This dual control on the nuclear side by the A.E.A. and what was the C.E.A. is creating special problems for the consortia who are building the stations. Queries which, on conventional stations could be solved by on-the-spot discussion between site engineers and the C.E.A. representative must now be referred back to committees and all this takes time as well as causing a lot of trouble. In some cases where real disagreement exists, the Generating Board representatives and the A.E.A. representatives are buying their experience fairly dearly and frequently at the expense of the manufacturer. In this interim period committee control would appear to be inevitable and desirable, providing financial adjustments are possible and real safeguards are made to prevent the system getting out of hand. The broader the body of experience in site construction, the better for the country as a whole and particularly at this stage it is more important that construction should be sure rather than speedy. This is not a state of affairs, however, that can continue indefinitely and only time will show whether the C.E.G.B. can operate efficiently with the new set-up and is able to work out a less cumbersome system of supervision while still continuing collaboration with the Atomic Energy Authority.

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Technical Education

THE problem of providing sufficient technically trained men to fill the ever-increasing number of technical posts continues to exercise the minds of many public figures. In the United States, the training traditions of the country have been thrown into relief by the recent Russian satellite programme and by the failure of the first Vanguard. It seems unfortunate that, in matters of education, it is the military programme which appears to spark off any real enthusiasm for tackling this problem seriously and that our educational system is assessed not in terms of absolute value so much as in military terms competitive with the U.S.S.R. Whatever the motives, however, in the midst of the talks and discussions, some positive action is being taken.

In addition to directly training scientific people, there is a need to utilize more efficiently the capacities of those who have been trained in the humanities or who have specialized in scientific subjects at present not in popular demand. A welcome move to provide higher education for children who show not only academic capacity but high personal qualities has been introduced under the title of the Trevelyan Scholarship, sponsored by industrial companies in consultation with representatives from Oxford and Cambridge and public and grammar schools. These scholarships, valued at £450 p.a., will be awarded to students who have pursued a broad range of studies in the sixth form and who show evidence that first, an honours course would be profitable and second, some exacting task or project has already been undertaken.

In the technical branches, it is vital that, in addition to a technical education, there is a broad background of training. Machine-made scientists are only useful in limited numbers. It is more important that a man has been trained to think than that he has been given specific knowledge. This is sometimes overlooked by people who only compare numbers in this country with numbers of scientists in the U.S.S.R. Our atomic energy achievements prove that quality is more important than mere quantity.

Geneva 1958

(*September* 1—13)

ALTHOUGH one cannot expect the Second International Conference on the Peaceful Uses of Atomic Energy to have quite the same world-wide impact as the first, there seems little doubt that September will see a great gathering of international scientists and technicians at Geneva. The conference, together with an exhibition in the Palais des Nations, is sponsored by the United Nations; the governments of member countries are responsible for the preparation of papers and the U.N. exhibition will be set up by those government authorities and commissions which are responsible for atomic energy development.

In addition, an important commercial exhibition will be staged concurrently in the Palais des Expositions, at which industry will have an opportunity of showing the world recent developments in power and research reactor engineering. The co-ordinating body in this country is N.E.T.A.C. (The Nuclear Energy Trade Association Conference) which has reserved an area of 20,000 sq ft. We understand that the majority of this is already booked, but should the demand for further space be significant, arrangements can still be made for an extension to the U.K. allotment. The British reaction to the exhibition has been enthusiastic and there is little doubt that an impressive showing will result. Reports on the response of American industry have been conflicting. An option was taken out on 20,000 sq ft but whether this will be used to the full seems to be in doubt.

Whereas at the first conference in 1955 some companies were prepared to advertise merely schemes, this exhibition obviously calls for a more solid demonstration of development progress. British companies are in the main better placed than their U.S. counterparts because of the full scale power station building now in progress with many main sub-contracts now coming up for initial deliveries. Furthermore, the swing towards the Calder-type reactor promises a real market abroad whilst the pressurized water system has yet to be fully proved. The commercial representatives of overseas countries were, in 1955, in greater evidence than might have been expected at what could have been largely a scientific fencing match; this year it seems likely that the commercial side will be of even greater significance, possibly overshadowing the scientific side.

This is not to say that the conference aspect should be disappointing—far from it. Although in 1955 much more information was released than expected and the way was opened for a much more liberal attitude towards declassification through other channels, the experience that has been gained in the intervening two years will allow a more down-to-earth approach towards current problems with a pre-knowledge that there is as much to learn as to disclose. The prestige that was attached to the 1955 conference will apply equally to the second—although not necessarily to a third—and contributors to the papers will be anxious to present up-to-date authoritative work.

It is particularly unfortunate, therefore, that in this country authors of papers are being selected on what appears to be a somewhat arbitrary basis and in what appears to be a secretive manner. The U.S.A.E.C. on the other hand has deliberately cast its net wide and requested suggestions from all leading establishments, manufacturing and operating companies, research organizations, universities, institutions, etc., to ensure a genuinely representative selection. The U.K.A.E.A. seems to regard it more as a private show, however, and the contribution from industry, in spite of the considerable development work in progress, will be meagre in comparison.

Commentary

Italy

The responsibility for electricity generation in Italy is vested in a number of inter-related organizations which are controlled and financed by both the government and manufacturing companies. The predeliction for using initial letters to describe these organizations tends to confuse the British observer particularly as the resultant words are somewhat similar.

The official government body responsible for nuclear research and development in Italy is the Comitato Nazionale per le Ricerche Nucleari (CNRN), established in 1952. Legislation to cover the industrial application of atomic energy has so far not been finalized and the exact terms of reference of this organization are therefore difficult to determine and are liable to changes. CNRN is, at present, working in conjunction with the Commissione No. 25—Energia Nucleare set up by the Associazione Nazionale Imprese Produttrici e Distributtrici di Energia Elettrica (ANIDEL) to study technical and organization questions, in the preparation of recommendations on safety, reactor siting, nuclear terminology, etc. A heavy-water research reactor similar to CP-5 is under construction at Varese and this will be the main experimental tool of CNRN. The reactor is being supplied by A.C.F. Ind. Inc. with engineering services by Vitro Corp. and is scheduled for operation in 1958.

In addition to Commission 25, ANIDEL has set up a Commissione Speciale per l'Energia Nucleare to examine problems of industrial policy.

In the industrial power field there are four main organizations:—SELNI, SORIN, AGIP, SENN.

SELNI

The Società Elettronucleare Italiana, Milano, with a capital of L500M was established in 1955 and although capital was initially divided amongst all the electrical groups, the company is now owned by the electrical firms of the north and centre of Italy, with a majority holding by Edison. Edison, since 1955, has been studying the possibilities of nuclear power and has been discussing alternative designs with both American and European countries. In December, 1956, Edisonvolta arranged a preliminary agreement with Westinghouse of America concerning the supply of materials to construct a station similar to that to be built at Rowe, Massachusetts for Yankee Atomic Electric Co. with an output of 134 MW. This Yankee plant is scheduled for operation in 1960 and incorporates a pressurized water reactor which will be based on Shippinport experience. Superheating by fossil fuel can increase the overall power to 240 MW. In April, 1957, the Edisonvolta project was fused into the programme of SELNI and Messrs. Gibbs and Hill were appointed as consultants to pursue the programme. The time scale which should be allotted to the programme, however, must presumably await finalization of the Yankee design.

SORIN

Società Ricerche Impianti Nucleari, Milano, with a capital of L2,000M was formed in the autumn of 1956 by Fiat and Montecatini as joint equal owners. These companies are both manufacturing and supply concerns. SORIN, in addition to its power plans, is engaged on a comprehensive programme of research and a swimming pool reactor is being supplied by A.M.F. of America.

On the power side, both the pressurized water reactor and the gas-cooled, graphite-moderated reactor are under consideration. At the end of July, 1957, Fiat concluded an agreement with Westinghouse covering the construction of pressurized water reactors. Under the agreement Fiat are given access to designs and would manufacture under licence to Westinghouse. It is believed that a similar agreement is being negotiated with one of the U.K. consortia.

AGIP

Società AGIP Nucleare, Milano, was formed in 1957 with a capital of L500M and is a wholly owned subsidiary of the government group ENI. It, in turn, controls two further groups SOMIREN and SIMEA. The first of these is interested in the chemical and mining aspects of the industry whilst the second has arranged an agreement with the Vitro Corp. of America concerning the design and the construction in southern Italy of a pressurized water reactor with an output of 150 MW.

On November 20, 1957, an announcement was made of an agreement between AGIP-Nucleare and the Nuclear Power Plant Company, England. Extracts from the text read as follows:—"The Nuclear Power Plant Company Ltd. have received from Ing. Mattei, President of Ente Nazionale Idrocarburi, Rome, a letter of intent to negotiate the construction of nuclear power stations in Italy, and also to conclude a long-term agreement for mutual co-operation on the design and development of power reactors. The agreement will be made between N.P.P.C. and AGIP Nucleare, a subsidiary of ENI, and will refer to reactors of the gas-cooled type. Throughout the negotiations, both parties have had the co-operation of the United Kingdom Atomic Energy Authority.

The first station to be constructed under this arrangement will have an output of 200 MW and will involve the manufacture in the United Kingdom of considerable quantities of plant. The Nuclear Power Plant Company will be responsible for the overall design and satisfactory commissioning of the station, while AGIP Nucleare will place local contracts and will carry out the site operation."

SENN

Società Elettronucleare Italiana, Rome, was established in 1957 with a capital of L1,000M contributed largely by electricity concerns which themselves are chiefly financed by the government. In addition to planning a 150 MW station to be sited about 100 miles north of Rome, the company, with government backing, aims to foster development along a broad front principally to ensure that the Italian engineering industry gains the maximum experience possible. The SENN project, developed with the assistance of the Internuclear Co. was put up to the World Bank for financial backing and won approval. The project is now

dubbed ENSI (Energia Nucleare Sud Italia) and the government authority CNRN is the responsible body. The World Bank (Banca Internazionale per la Ricostruzione e lo Svi luppo) has formed an international committee under the chairmanship of W. B. Lewis of Canada, comprised of representatives from Italy (one), United Kingdom (two), U.S.A. (two), France (one), to consider proposals and choose a type and constructional company. Tenders for the station are to be submitted by April 15, 1958. SENN has retained the services of Kennedy and Donkin, London, as consulting engineers. Twenty companies have expressed an interest in the station—two French, one Canadian, one Belgian, eleven American and the five U.K. Consortia.

Power Demands

Demand for electrical power increased in Italy by an annual amount averaging 7% in the years 1922-1955 and rising to 9% in the 1950-1955 period. Even assuming further increases do not exceed 7%/an. demand will reach 76,000M kWh in 1965 and 152,000M kWh in 1975. In 1956 the hydro and geothermal contribution amounted to 82%; these resources are estimated at 60-66% of the total commercially exploitable. Assuming that these are in full production by 1965, a further 26,000M kWh must be generated by steam plant. Reserves of fossil fuel are small and an immediate start is therefore required on the nuclear programme. Present policy leans towards the investigation of both the Calder and PWR systems with a programme geared to 3,000 MW by 1965/7.

Generating costs will exceed those experienced in the U.K. Due to higher investment rates (7%) and a faster amortization rate (7%) the relatively high capital cost of the nuclear station is of even greater significance in Italy. Capital charges are likely to be some 35-40% greater than for the equivalent C.E.A. stations and could lead to a final price per kWh sent out some 20-30% higher than experienced in the conventional Italian stations working on natural gas—even assuming reasonable burn up of the fuel and a high load factor. Nevertheless, it is likely that the participation of Italian industry will influence the final figures and by 1962 when the first stations will come into operation the generating costs will not differ a great deal from those experienced in conventional stations. This will be assisted by a lowering of capital cost/kW installed with increased size of station, increase of conventional fuel costs and probably a lower negotiated foreign investment rate.

All these projects are subject, of course, to bi-lateral agreements having been negotiated with the appropriate exporting company. The U.S. has already signed such an agreement which assures the supply of 7,000 kg U^{235}.

Evaluation

It is clear that there is, in Italy, a strong desire to invest in a nuclear power programme but there will be no crash buying. Italian companies are anxious to build up experience and progressively take over more and more of construction. Of the projects in hand, the AGIP-N.P.P.C., although still some way from finalization, seems the most likely to be off the mark first, if only because of the advanced state of Bradwell. SELNI may, of course, go ahead with the Yankee type sooner than expected but it would seem that a number of technological problems remain to be ironed out before even designs and, therefore, costs, can be finalized. The SENN project will have massive backing and the full advisory services of the A.E.A. and the A.E.C. but it is difficult to see how agreement can be reached by the committee with any speed and the preliminary evaluation could well take many months. What should not be forgotten is the additional negotiations going on with U.K. companies who have stations under construction in England and Scotland. These could be finalized almost as soon as the AGIP agreement, and we may well see three Calder-type reactors actually under construction in Italy by the end of the year.

"Nuclear Engineering" Monographs

WITH the widening interest in the whole subject of atomic energy there has arisen a need for a series of publications giving essential background knowledge. Students at universities and technical college and engineers who, while proficient in certain branches require additional proficiency in allied fields, frequently find that specialist publications give a deeper treatment than is required. The cost, for students particularly, is often embarrassingly high.

To meet this need, Temple Press Limited, publishers of *Nuclear Engineering*, are launching, early in February, a series of monographs, under the general editorship of W. K. Mansfield, designed to cover the general field of nuclear engineering. The first three titles to be published simultaneously in February are as follows:—

"Elementary Nuclear Physics"—by W. K. Mansfield, B.Sc., Lecturer in the Nuclear Engineering Laboratory, Queen Mary College, University of London.

"Nuclear Reactor Theory"—by J. J. Syrett, B.A. (Reactor Division, A.E.R.E., Harwell).

"Reactor Heat Transfer"—by W. B. Hall, B.Sc.(Eng.), A.M.I.Mech.E., Research Manager at the Windscale Research and Development Laboratory, U.K.A.E.A. I.G.

Care has been taken to keep the cost of these publications as low as possible and it is proposed to publish new editions periodically in order to ensure that the information contained, whilst providing a broad treatment leading up from elementary principles, nevertheless includes up-to-date summaries of more advanced theories.

It is believed that this series of monographs will provide an invaluable fund of basic information for the newcomer to the field and a reference library for those firmly established in the field who require to brush up their knowledge of subjects that are not their own.

Buyers' Guide Number

THE February issue of *Nuclear Engineering* will be a special Buyers' Guide number in which companies manufacturing specialized components are listed under classified headings. Selection of the classifications has not been easy, as a very considerable fraction of British industry is now manufacturing equipment applicable to nuclear power stations which contain so much conventional equipment. The classifications have been chosen to cover equipment peculiar to the nuclear field and some more conventional equipment which is of particular current interest. It should be emphasized that the number included has been vigorously edited to keep within the bounds of available space, and many companies who are making an invaluable contribution to the power and research programme for it have had to be omitted. The classifications do not by any means define the limits of our interest, but are believed to represent the maximum cross-section of interest, at this present time. We shall welcome any comment on the classification headings and suggestions for alternative terms in future guide numbers.

Index

THE Index for the 1957 volume of *Nuclear Engineering* is included as an insert in this issue. Because it is not stitched in, it has been necessary to reduce the size of the page, but a limited number of uncut copies are available for those wishing to include them in bound copies.

Relay Circuit Analysis—

A New Approach

By J. J. SMITH

The fail-safe philosophy in control systems demands a new approach to relay circuit evaluation. Whilst not claimed to be mathematically exact, the following analysis aims at providing a method of rapid comparison of circuits to determine to what extent additional safeguards introduce additional weaknesses.

OVER the past number of years considerable discussion has taken place on the subject of logic and relay circuits, or Boolean algebra applied to the design of relay circuits. Whether or not this logic continues to be used in the design of relay circuits, it has been, and should remain, a useful method of reducing certain types to a minimum number of contacts, or operating paths, necessary to perform the circuit functions.

It is an important factor in the design of relay circuits to reduce the number of contacts to a minimum, not only to reduce the economic structure of the circuit, but perhaps, what is more important to the user, to have the minimum number of operating paths to perform one particular operation. It will be appreciated that the ideal condition in fault finding is to have only one path over which a circuit can be completed from one group of relays. This makes servicing very much easier than if the circuit is repeated in another form, by the same relays. It is also desirable not to have contacts of the same relay repeated in a series circuit, as this tends to increase relay fault liability unnecessarily. Often, the examination of a circuit will show that one contact can supply a common condition to a number of branches of the circuit, saving contact units on a particular relay and obviating the necessity of providing a "slave" relay.

Boolean algebra will lead to a circuit which is simplest in form but in nuclear instrumentation this is of secondary importance to 100% reliability. It is essential when designing reactor control networks that all circuits should fail to safety. At the same time unnecessary shut-downs due to spurious trips must be reduced to the absolute minimum. This second criterion is in itself quite a problem because the more the designer tends to make his circuit fail safe the more prone it becomes to spurious shut-down, and the more he guards against spurious shut-down, the less sensitive the circuit can become to the actual stimuli condition. Some system must be devised therefore to determine to what extent, in the designer's attempts to strengthen a circuit, he actually weakens it.

Common Faults

The most common fault encountered in relay operation is failure to close (make), due to corrosion of the contacts or the deposition of dust between the contacts. This is particularly prone to happen in circuits which are little used as some self-wiping takes place when the relay operates. A reactor safety circuit, of course, may operate relatively frequently during the commissioning trials but may then run for many months without a single operation.

Safety circuits (except in a section where it is virtually impossible to do otherwise) are never designed to rely on a "make to safety" system but are always built so that in a reactor fault condition the appropriate relay is de-energized and the circuit breaks, by opening contacts.

A made circuit can, however, fail to break when the relay is de-energized if the contacts are welded or the armature is damaged; the first of these causes only is significant.

In analysing the response of a system of contacts and the probability of spurious trip, consideration must be given also to the contact that has never made resulting in one arm of the circuit being inoperative.

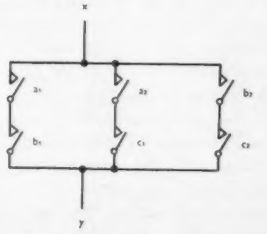


Fig. 1.

It should be noted that in the following discussion relay failure will not be included and the analysis will be confined to the contacts, which may, therefore, be considered independent whether they are operated by common armatures or not. The examination of various network designs aims at deriving a value which can be assigned to individual contacts in a given circuit. Similarly, the overall value of a circuit is calculated in terms of the contacts.

Fig. 1 illustrates a symmetrical two out of three trip circuit. This contact arrangement caters for the condition where any two of three channels must fail (release) to break the circuit xy. Now assume that, due to a fault, contact a_1 fails to close, the fact that it is open circuit is not apparent and will have no ill effect on the circuit xy. The failure of the circuit maintaining A or B (A relay, B relay with contacts a_1 to a_n and b_1 to b_n) energized will not open the circuit xy, but should C be released, the circuit xy will be broken.

It can be seen that the disconnection of contact a_1 will reduce the effectiveness of the circuit arrangement to that shown in Fig. 2 and the genuine failure of C will still ensure an open circuit between points x and y.

This argument traces the result of contact a_1 failing to close. The susceptibility of the contact to this form of failure is denoted by k_d (a_1) and that due to the failure of a contact to open as a result of shorting will be denoted by k_s. The overall circuit susceptibility to these two types of failure will be denoted by K_d and K_s.

Considering a circuit consisting of two contacts in series the circuit susceptibility to a disconnection (i.e. failure to

make) is greater than for a single contact, and numerically can be expressed as follows:—

putting $k_d=k_s=1$
$K_d=2$

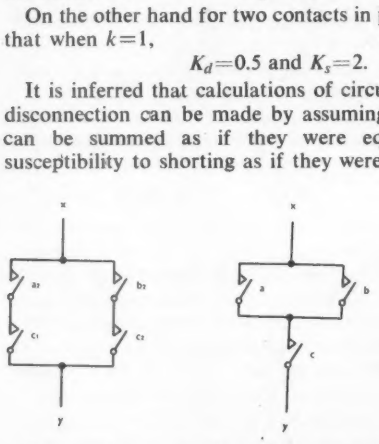
whereas the circuit is half as susceptible to shorting,

i.e. when $k=1$ $K_s=0.5$.

On the other hand for two contacts in parallel it is argued that when $k=1$,

$K_d=0.5$ and $K_s=2$.

It is inferred that calculations of circuit susceptibility to disconnection can be made by assuming that the contacts can be summed as if they were equal resistors and susceptibility to shorting as if they were equal condensers.



(Left) Fig. 2.

(Right) Fig. 3.

Conversely a single circuit can be analysed into individual contact susceptibilities but whereas for the circuit the disconnection susceptibility follows a resistor rule, the contact disconnection susceptibility follows a condenser rule. Similarly to analyse for contact shorting susceptibility the analogy is made to resistors, as against condensers for the overall circuit shorting susceptibility. It is assumed initially that all contacts are weighted equally but this needs modification when multiple circuits are being examined. It can be shown for single circuits that k_s is always the reciprocal of k_d for an individual contact, and K_s is similarly the reciprocal of K_d. This is no longer true when multiple circuits are analysed as contacts dependent upon the operation of other relay circuits carry not only an inherent susceptibility but in addition the susceptibility of the operating circuit.

Returning to Fig. 1, if $K_s = K_d = 1$, then each contact in the group will have a disconnection susceptibility of $k_d = 0.66$. This can be deduced directly by noting that as there are three paths contributing to continuity xy, each path contributes $\frac{1}{3}$, and each contact in each limb will contribute $\frac{2}{3}$.

Consider now the condition where a_1 has failed, and the circuit is as shown in Fig. 2. By applying the same logic, each contact will now have a value of $k_d=k_s = 1$.

If, however, a circuit to give the same operational facility as that in Fig. 2 had been designed without reference to Fig. 1 it is more probable that the result would have been that shown in Fig. 3.

In this case the contacts would be valued at: $k(a)=1$, $k(b) = 1$ whilst $k_d(c) = 2$ and $k_s(c) = 0.5$. Furthermore, should A or B, but not both, fail the circuit xy will be unaffected. It can therefore be said that a spurious release of a or b can be tolerated, but on no account can a spurious release of c go unnoticed. Its value $k_d(c) = 2$ indicates its susceptibility to disconnection in the circuit, and it would appear to be an advantage to arrange the circuit as in Fig. 2.

With a simple parallel contacts arrangement when K is put equal to unity, the highest possible value for each contact can only be $k_d = 0.5$ compared with the lowest possible value of $k_d = 2$ for a series circuit (two contacts are minimum arrangement). Conversely in the two cases k_s=2.0 and 0.5 respectively. It can, therefore, be assumed that a contact having a value lower than $k = 2$ but higher than $k = 0.5$ represents a reasonably safe contact, or at least one which can be compared with the ideal condition of a contact which is impervious to spurious open or short circuit (if this were possible).

Reactor Control Circuits

A practical example will now be considered in which a certain condition is required to shut down a reactor in the event of this condition exceeding a certain predetermined level. The instrument relay contact can be arranged in

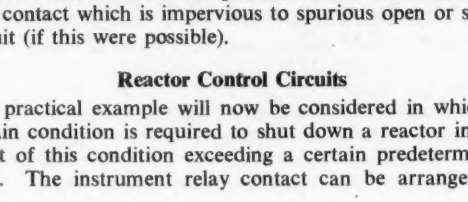


Fig. 4a.

series with other instrument relay contacts to release a relay capable of controlling the reactor power or shutting it down completely. To ensure no doubt exists, and that the reactor will shut down, more than one line of contacts can be arranged, any one of which opening will trip the reactor. This has the advantage of guarding against a fault on one line preventing it from opening, but it has also the disadvantage of increasing the possibility of spurious trip. In the case of a circuit to trip a reactor, it is considered most important to cause the reactor to trip under all genuine fault conditions, even at the expense of probable spurious trip, but the degree to which the possibility of spurious trip can be allowed must be specified. As has been stated, there are two possible conditions which will cause a circuit to fail: (1) when a contact fails to make, or becomes open circuit and (2) when a contact fails to open, due to the contacts welding thus preventing the opening of the circuit.

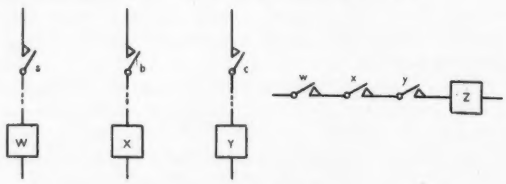


Fig. 4b.

In Fig. 4a, when the value of $k(a) = 1$, then $K_d(X) = 1$ and similarly $K_d(Y) = 1$ and $K_s(X) = K_s(Y) = 1$.

Contacts x and y each have an inherent susceptibility equal to that of a and b, i.e. a value of $k = 1$, but they also receive an additional unit of susceptibility from the preceding circuits and the sum value for each contact will be 2.

It can be seen from the circuit that not only is the Z circuit susceptible to disconnection (or failure to close) due to contacts x and y but it could also be opened by a fault on contacts a and b.

Therefore $k_d(x) = 2$; $k_d(y) = 2$ and $K_d(Z) = 4$ (summing as for resistors).

Similarly the Z circuit is susceptible to failure-to-trip due to contacts x and y as also a short in a or b.

Therefore $k_s(x)=2$; $k_s(y)=2$ and $K_s(Z)=1$ (summing as for condensers).

The complete analysis for Figs. 4a-4e is given in Table 1.

From these calculated values of K_d and K_s it can be seen that the circuit in Fig. 4b produces a lower value of

K_s than that of the previous circuit arrangement, which has a value $K_s = 1$ and its response to genuine trip is better (there now being three lines, the release of any one will cause a trip). This, however, is of little advantage over the arrangement of two guard lines in Fig. 4a, as the probability of spurious trip is very much greater, but from it, further development can produce the circuit shown in Fig. 4c. Although basically the same as Fig. 4b, the contacts of W, X and Y are arranged in two out of three coincidence circuit arrangement to operate Z whereby two guard lines must open to release Z. The result obtained by this circuit is $K_d(Z) = 1.33$ although $K_s(Z)$ has now increased to 3.0 showing a greater tendency to fail to trip as a result of a genuine stimulus.

It will be noted that the number of contacts required on the instrument relay has been increased in the last two examples, and by the addition of one contact has now produced a decrease in K_d from 4.0 as in Fig. 4a to 1.33 in

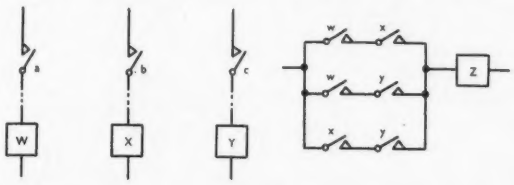


Fig. 4c.

Fig. 4c. If the number of instrument contacts is increased by twice, a circuit shown in Fig. 4d can be produced which allows one monitor circuit to be taken out of service for maintenance purposes without shut-down of the reactor.

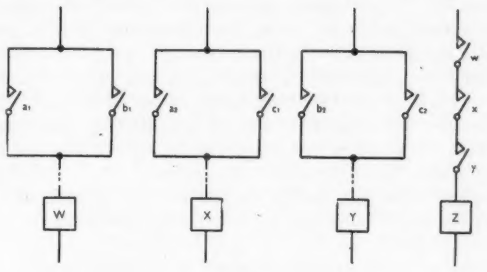


Fig. 4d.

Treating the contacts as condensers of unit value gives a circuit value of 2,

i.e. $$K_s(W)=K_s(X)=K_s(Y)=2.$$

Translating this to the contacts, x, y and z and adding the inherent susceptibility

$$k_s(w)=k_s(x)=k_s(y)=3.$$

Therefore $$K_s(Z)=1.$$

Conversely taking the resistor analogy

$$K_d(W)=K_d(X)=K_d(Y)=0.5$$
$$k_d(w)=k_d(x)=k_d(y)=1.5$$
and $$K_d(Z)=4.5.$$

It is not possible here to arrange the contacts of W, X and Y in a two out of three coincidence arrangement (which would necessitate all three instrument contacts opening to release Z) and their contacts must be arranged in a series chain, giving a result of $K_d(Z) = 4.5$. Examination of this circuit will show that although under normal conditions a minimum of two guard lines will open to trip the reactor, it is only necessary for one guard line to open spuriously to cause a trip.

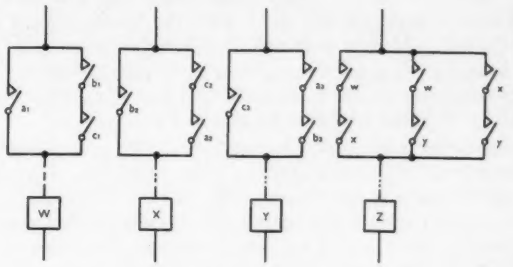


Fig. 4e.

Fig. 4e shows a circuit where it is possible to remove the instrument relay from the circuit, or one complete guard line and maintain the reactor operational. The combination of these two facilities necessitates the use of an additional monitor contact in the guard line, and the susceptibility of the circuit shows a marked decrease K_d falling to 1.11. Unfortunately K_s has risen to 3.75.

The arrangement whereby W, X and Y have their contacts in a two out of three coincidence circuit can be accepted as good practice, mainly because it is reliable under normal trip conditions, but also because it guards against spurious trip. The contacts of A, B and C allow one instrument relay to fail spuriously, but what is, perhaps, more important should any one contact become short-circuited, only in the case of a_1, b_2 and c_3 will it prevent a guard line from release.

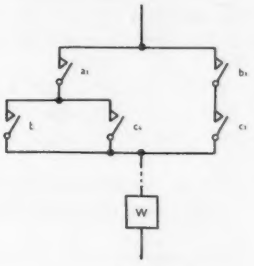


Fig. 5a.

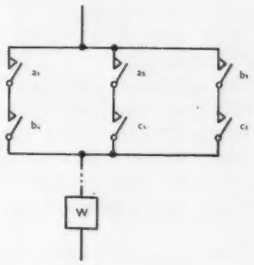


Fig. 5b.

It is important here to examine each contact value and the circuit can be broken down as follows, considering now each contact as a capacitor:—

if $K(Z) = 1$, then $k_d(w) = 0.66$; $k_d(x) = 0.66$ and $k_d(y) = 0.66$

if $K(W) = 1$, then $k_d(a_1) = 0.5$; $k_d(b_1) = 1$ and $k_d(c_1) = 1$.

(Similarly for guard lines X and Y.)

The instrument contacts of A, B and C are predominantly $k = 1$. The three contacts with a value of $k_d = 0.5$ and $k_s = 2.0$ are the weak contacts. These contacts, if welded together, could prevent the release of a guard line but the failure of more than one to perform normally at any one time is extremely improbable.

Table 1

Circuit	$K_d(Z)$	$K_s(Z)$
4a	4	1
4b	6	0.66
4c	1.33	3
4d	4.5	1
4e	1.11	3.75

To take the design of this circuit to its extreme, however, a protection can be provided to overcome the possibility

of this type of failure. Fig. 5a shows the group of contacts which could be included in guard line W circuit, the circuits for X and Y being similar.

Contacts b_4 and c_4 protect the guard line against the short circuit of contact a_1 by ensuring the a_1 branch of the circuit is broken if both A, B and A, C release.

In doing this a basic two out of three coincidence circuit has developed and if $K(W)=1$, then $k(a)=1$; $k(b_1)=1$; $k(c_1)=1$; $k_d(b_4)=0.5$ and $k_d(c_4)=0.5$.

Again there are two weak contacts in the group and by rearranging the circuit to that shown in Fig. 5b, each contact takes a value of $k_d=0.66$.

It is also interesting to note that by adopting this arrangement Fig. 5a or b, the genuine failure of two parameters will cause the release of three guard lines monitored by W, X and Y, which is of considerable advantage over the arrangement shown in Fig. 4e, where two parameters failing cause the release of only two guard lines.

Whilst the facility of the circuit has been improved by the adoption of 5a and 5b the circuit analysis yields results of $K_d(Z)=1.25$, $K_s(Z)=3.25$ and $K_d(Z)=1.11$ and $K_s(Z)=3.75$ respectively which are closely comparable to the simpler circuits of 4c. Furthermore the contact analysis of 4c gives $k(w)=k(x)=k(y)=1$; i.e. no weak contacts.

Two Out of Three Circuit

The " 2 out of 3 " is hypothetically good; not only does it cover the possibility of one of three conditions failing to open, but allows one condition to open spuriously. Its general acceptance in reactor safety circuitry is based on the assumption of the improbability of occurrence of two simultaneous faults.

If Fig. 1 is examined for values of susceptibility, we find $K_d=0.66$ and $K_s=1.5$. This indicates that the circuit is more susceptible to shorting and failing to trip than to disconnection.

The algebraic representation of this circuit is (by the Montgomery method): (a + b) (a + c) (b + c) where the + sign indicates a series connection, and the circuit has a parallel characteristic.

If (as is possible with this circuit requirement), the contacts are arranged with a series characteristic, the equation will be: ab + ac + bc, forming a circuit in which $K_d=1.5$ and $K_s=0.66$.

It is evident from both the circuit and the values of K_d and K_s that this arrangement is more susceptible to disconnection (such as corrosion) than shorting and would appear more suitable in a trip circuit.

There is no simple explanation why the parallel characteristic circuit has been accepted as standard practice in safety circuitry. One relevant argument concerns the failure probability. The probability of two series contacts in any one parallel limb welding at one instant is extremely small, possibly much more so than two parallel contacts in the series characteristic circuit becoming open circuit. But occurrence of these improbable faults in the parallel circuit would prevent a genuine trip, whereas in the series circuit they would not affect a genuine trip, but would cause a spurious trip.

It would seem opportune therefore to re-examine the use of the two out of three circuit with a view either to substituting the series circuit or using it in combination with the parallel circuit. For example, if now in Fig. 5b the W, X and Y circuits are made into series circuits the associated Z circuit remaining a parallel, then

$$K_d(Z)=1.66 \text{ and } K_s(Z)=2.5$$

whereas if the Z circuit is converted to a series two out of three, the X, Y, Z circuits remaining parallel, then

$$K_d(Z)=2.5 \text{ and } K_s(Z)=1.66.$$

Conclusion

Ideally it would be desirable to assign maximum values to the derived circuit and contact susceptibilities, with which any reactor safety circuit must comply. Specific values must, however, be a function of the type of relay employed, of the environment in which the relays operate and of the testing and maintenance practice adopted, but a low value must be the design aim. As a method of circuit evaluation the analysis shows up the built-in weaknesses, whether these be a disproportionate dependency on one contact, an overall proneness to spurious trip or a liability to fail to trip. The system facilitates rapid comparison of different circuits designed to fulfil similar functions.

Contacts de Relais et Leur Valeur

L'emploi général de relais dans les circuits de commande de réacteur a nécessité un nouvel examen de l'établissement des circuits de relais. Le fonctionnement d'un réacteur demande que les circuits doivent toujours " manquer sans danger " mais en même temps un déclenchement excessif du réacteur dû à de fausses manoeuvres doit être évité.

Dans le passé la logique de relais a été employée pour développer des circuits qui soient les plus simples possibles pour accomplir la fonction donnée. Il faut admettre une nouvelle philosophie donnant une sécurité de 100%. L'article discute la valeur qui doit être attribuée à un contact de relais dans un circuit donné du point de vue de la susceptibilité de défaut et de la susceptibilité conséquente de défaut du circuit. Divers systèmes sont analysés, le " deux de trois " étant pris comme le meilleur compromis en ce qui concerne la certitude avec le minimum de faux fonctionnement.

Relaiskontakte und deren Wert

Aus der weitgehenden Verwendung von Relais in Reaktorsteuerkreisen ergaben sich ganz neue Gesichtspunkte für Aufbau der Relaisschaltungen. Der Reaktorbetrieb verlangt absolut sicher reagierende Schaltungen, andererseits ist aber allzu häufiges Ausschalten des Reaktors infolge von Nebenursachen unerwünscht.

Bisher ging die Entwicklung der Relaisschaltungen folgerichtig dahin, sie für Ausüben der gegebenen Funktion so einfach wie möglich zu gestalten. Um 100%ige Zuverlässigkeit zu erreichen, müssen neue Konzeptionen herangezogen werden. Der Artikel behandelt den Wert, der einem Relaiskontakt in einer gegebenen Schaltung unter Berücksichtigung der Anfälligkeit gegen Versagen, und damit der Suszeptibilität der Schaltung selbst gegen Versagen, beizumessen ist. Es werden verschiedene Systeme analysiert, wobei das System " zwei von drei " als beste Kompromisslösung für Zuverlässigkeit bei seltenstem ungewolltem Ansprechen bezeichnet wird.

Contactos de Relai y su Valor

El uso extenso de relais en el circuito de control de un reactor ha exigido el estudio de nuevas ideas en el diseño de circuitos de relais. La operación del reactor exige que los circuitos deben siempre " fallar seguros," pero al mismo tiempo se debe evitar el excesivo disparado, debido a causas espurias, del reactor.

En el pasado, se ha empleado la " lógica del relai " para evolucionar circuitos que son los más sencillos posibles para desempeñar la función determinada. Se tiene que admitir una nueva filosofía que ofrezca un 100% de seguridad. El artículo discute el valor que se debe atribuir a un contacto de relai en un circuito determinado del punto de vista de susceptibilidad a falla, y la consiguiente susceptibilidad a falla del circuito. Se analizan los diversos sistemas, tomándose el " dos de tres " como el mejor término medio para la seguridad con el mínimo de funcionamiento espurio.

The Metallurgy of BERYLLIUM

Its Nuclear Applications

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The favourable nuclear properties of beryllium could lead to its widespread application in reactor technology. This article discusses the chemical and metallurgical problems associated with the production and fabrication of the metal, and details the properties to be expected of the finished components.

PROBABLY the most important single property of any material intended for the core area of a nuclear reactor is its absorption cross-section for thermal neutrons. Beryllium metal is unique in that it has the lowest value of all metals, being approximately one-sixth of its nearest rival, magnesium. This property combined with its high scattering cross-section and its high atomic density make it an excellent constructional material for moderators and reflectors, where its application is associated with the decreased critical mass of the assembly. It has been extensively used in the U.S.A.E.C. Materials Test Reactor, which is designed to operate at peak neutron fluxes of about 5×10^{14} neutrons/cm^2-sec in the beryllium reflector; another application has been in the U.S.A.E.C. Submarine Intermediate Reactor.

The high strength to weight ratio of the metal, particularly at elevated temperatures, combined with its good resistance to corrosion, make it an attractive proposition for other applications where these characteristics are important. Fig. 1 compares the mechanical strength of the metal with a number of other materials. However, its ductility at room temperature is poor, and it is a brittle metal from an engineering standpoint, and this has severely restricted its application to nuclear power production. There can be no doubt that the resolving of the metallurgical difficulties experienced at present, particularly with respect to the question of poor ductility would have a tremendous impact on its application to nuclear and other purposes.

Technological difficulties in extraction and fabrication have resulted in the price of the metal being high, and this has been an additional factor limiting its use. Its nuclear application is, nevertheless, rapidly increasing and the lowering of price resulting from increased usage is reflected in the approximate price of $47 per pound of as-cast ingot quoted for present-day contracts.[1]

Further minor applications of the metal associated with its nuclear properties are related to the construction of neutron sources, where use is made of its capacity to produce neutrons when bombarded with alpha particles. It also finds use in the construction of X-ray windows.

A major application of the element is as a 2% alloy with copper, which absorbs over 80% (wt.) of present-day production. It should, however, be noted that this alloy is produced by direct reduction of the mixed oxides and does not involve the initial preparation of the pure metal.

Occurrence

Beryllium is a constituent of about 30 known minerals, but the only commercial source of the metal is beryl, which is a beryllium aluminium silicate containing approximately 4% wt. beryllium. This mineral is distributed in pegmatites, granites and syenites, of which the zoned pegmatite sources have formed the major source of supply. The density of the pure crystals is close to that of naturally associated gangue minerals such as silica and feldspars, and no

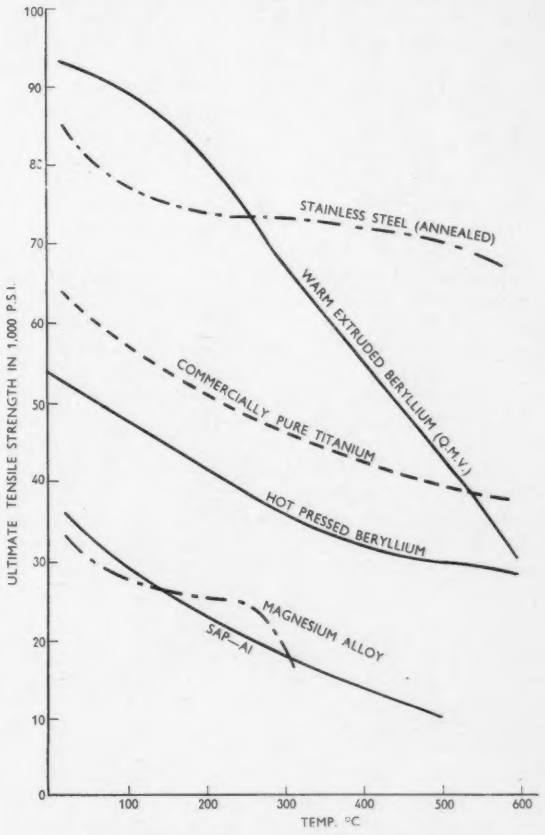

Fig. 1.—Comparison of the strengths of extruded Beryllium, hot pressed Beryllium, Stainless Steel, Titanium, Magnesium alloy and S.A.P. Aluminium.

mechanical methods are, as yet, available for concentration. The crystals must, therefore, be gathered by hand picking or "cobbing" and the supply has often been associated as a co-product with the extraction of tantalite, cassiterite and sheet mica.

Large reserves of ore bodies are available containing beryl in a form which is too fine for hand picking, and methods of concentrating these fine particles are being extensively investigated.[2] This would make possible the

recovery of beryllium from these deposits. The ore reserves have been estimated as 210,000 tons (short) of 1% ore and 3.5 million tons (short) of the 0.1% ore.[1] The average U.S. price of beryllium ore in 1953 was $47 per short ton unit BeO for ore containing about 10% BeO.

Extraction

The first stage in the production of the pure metal from beryl involves the production of pure beryllium hydroxide. Two processes are in use for this operation.

In the Copaur-Kawecki Process the ore is crushed to a suitably fine size and mixed with a suitable source of fluorine such as sodium silicofluoride or sodium ferric fluoride. The mixture is heated to about 750°C, resulting in the production of sodium beryllium fluoride, which is water soluble; the solution is subsequently treated with caustic soda to give insoluble beryllium hydroxide, which is washed and ignited to give BeO. The process is described in detail by Bryant.[3]

An alternative process developed by the Brush Beryllium Company is extensively applied in America and is based on the fact that if the beryl ore is melted and quenched, it is amenable to attack by sulphuric acid. A recent advance reported by Schwenzfein[4] is associated with the subsequent heat treatment of the quenched ore, which releases beryllium locked up in the silica and increases the yield of beryllium from 60% to 95%. After treatment with sulphuric acid the beryllium and aluminium are present as sulphates. The addition of ammonium hydroxide enables the bulk of the aluminium to be subsequently separated by crystallization as ammonium alum. Sodium hydroxide is subsequently added, to convert the beryllium sulphate and remaining aluminium sulphate to the beryllate and aluminate respectively. Both these salts are soluble in the cold alkaline solution. However, the beryllate decomposes on heating, giving beryllium hydroxide, and it makes possible a further separation from the remaining aluminium. The $Be(OH)_2$ can be converted to BeO by firing at about 750°C.

The end product from both these processes is BeO, and the need for further purification is dependent on the care taken in processing and the purity required for the next stage of metal production. Beryllium oxide for nuclear uses needs to be exceptionally pure.

Metal Production

Two major processes are currently in use for the production of the metal, and the metal produced by each method requires different forms of processing. Both techniques will, therefore, be described briefly.

Magnesium Reduction of the Fluoride. The first step is to convert the beryllium hydroxide to ammonium beryllium fluoride by treatment with ammonium bifluoride and/or hydrofluoric acid. Impurities remaining in the hydroxide, which may include manganese, copper, lead, arsenic, and aluminium, are then removed by a series of precipitations; after which beryllium ammonium fluoride is recovered by crystallization. The ammonium beryllium fluoride is subsequently heated to about 950°C to give pure anhydrous beryllium fluoride, the ammonium fluoride being returned to the cycle. In the reduction process, the beryllium fluoride is reduced with magnesium using an excess of beryllium fluoride to lower the melting point of the slag.

The reaction is carried out in a graphite-lined furnace, to which magnesium metal and beryllium fluoride are gradually added at a temperature of 900°C. The beryllium is formed as a fine powder dispersed in a slag of magnesium fluoride/beryllium fluoride. The temperature is raised to coalesce these particles and the charge subsequently poured into moulds. The beryllium is recovered as small "nuggets" or "pebbles" from the slag matrix. The metal contains an appreciable amount of magnesium and is relatively high in metallic impurities (2,500 p.p.m.).

Electrolytic Reduction of the Chloride. The production of beryllium by the electrolysis of the chloride was extensively practised by Degussa in Germany and a similar process is today operated by The Pechiney Co. of France. No details of the French technique have been released, but Bryant[3] has recently given a comprehensive account of the process as operated by Messrs. Murex Ltd. for U.K.A.E.A.I.G.

The production of the chloride is based on the chlorination of beryllium oxide in the presence of carbon in the following steps:

(1) Mix $Be(OH)_2$ with carbon and tar.
(2) Roast at 250°C for 4 hours to remove moisture.
(3) Recrush, mix with tar and extrude to cylinders 1-in. dia. by 1-in. long.
(4) Heat to 750°C to sinter and remove volatiles.
(5) Chlorinate at 900°C in a carbon tube to give crude beryllium chloride.
(6) Reduce iron to the involatile ferrous state by hydrogen reduction.
(7) Redistil to purify the crude chloride.

The pure beryllium chloride is then mixed with sodium chloride, or a mixture of sodium and potassium chloride, and electrolysed at 350°C giving a flake deposit of pure beryllium metal. The flake is separated from the electrolytic bath and leached with iced water to minimize reactions arising from the hydrolysis of the beryllium chloride contained in the adhering electrolyte. It is then washed with caustic soda and, finally, with nitric acid, centrifuged and dried. The major impurities are occluded electrolyte, carbon from the anode and nickel from the vessel used for electrolysis. The mean content of metallic impurities has been given as 500 p.p.m.

TABLE A

Chemical Composition of Beryllium Produced by the Major Extraction Routes

		O_2 %	Cl ppm	Al ppm	Fe ppm	Mn ppm	Ni ppm	Mg ppm	Si ppm	Cu ppm	Total Metal impurities ppm
Electrolytic reduction of chloride											
Crude flake	(a)	0.06	1,200	80	300	<60	20	<30	250	—	500
Crude flake	(b)	0.4	4,600	—	100	<20	560	—	—	—	750–1,000
Powder from milled and leached flake	(a)	0.85	300	—	300	—	—	<30	—	—	—
Powder from milled and leached flake	(b)	0.95	750	—	140	—	—	—	—	—	—
Vacuum melted flake		0.05	10	260	230	—	—	—	240	—	—
Magnesium reduced fluoride											
Technical grade beads	(c)	NQ		5,000	4,500	1,300	100	1.2%	500	5,000	3%
High purity beads	(c)	0.05		1,500	1,000	100	100	1.2%	500	500	1.5%
Vacuum melted beads	(c)	NQ		800	850	240	140	50	750	50	3–4,000
Powder from vacuum melted beads		0.85	<20	450	800	90	180	350	—	—	2–4,000

(a) Pechiney Flake.
(b) Beryllium Corporation of America Flake.
(c) Beryllium Corporation of America Typical analyses.

Comparison of Metal Extraction Routes

Comparative analyses of the two grades of metal produced are given in Table A. It will be noted that the oxygen content of the "as-reduced" metal is comparable for both methods, being of the order of 0.05% oxygen. Further, the powder from both sources is higher in oxygen, and may be as high as 1.0%(wt.), or more for the finer grades of powder. This increase is associated with the formation of oxygen as oxide films at the powdering stage. The chloride content of the electrolytic powder is high and Williams[5] gives details of leaching processes which are effective in the removal of these chlorides.

Vacuum melting is a possible alternative for the removal of chlorides from pure beryllium and is, in fact, practised by both the Russians[6] and the French. In this way the chloride is reduced to approximately 20 ppm. However, the melting operation has the disadvantage that further processing is required for reconverting the cast metal to powder, if it is to be fabricated by powder metallurgy methods.

The "pebbles" produced by magnesium reduction contain appreciable quantities of magnesium and magnesium fluoride which necessitates a vacuum melting operation for their removal. The vacuum melting is also stated to remove some of the metallic impurities.

The electrolytic process would thus seem to give metal that is rather purer than that given by the fluoride route, from the point of view of metallic impurities although, as will be seen later, there is no evidence that these levels of impurities materially affect the physical and mechanical properties of the metal.

Metal from both sources may, of course, be refined by vacuum distillation if this is considered necessary. This process is carried out at 1,300°C-1,400°C under a pressure of 1×10^{-5} mm Hg.

PHYSICAL AND NUCLEAR PROPERTIES

A detailed account of the nuclear properties of beryllium has been given by Stehn.[7] Readers wishing to follow this aspect in greater details should consult this very comprehensive paper.

Neutron Cross Section

The nuclear cross section of elements is a measure of the probability of collision of neutrons with nuclei and is considered with reference to two possibilities: (a) capture or absorption, (b) scattering.

The neutron capture or absorption cross section is defined in terms of the probability of capture or absorption by the atom concerned. It is expressed as the effective size or cross sectional area of the nucleus, the unit being the barn (10^{-24} cm^2/at.). The neutron absorption is inversely proportional to the velocity of the neutron and it should be noted that the absorption cross section is not directly related to the atomic dimensions; and that values for isotopes may be very different one from the other.

The scattering cross section, which is expressed in the same units, gives a measure of the ability of elements to scatter neutrons. The cross sections are again dependent on neutron energy. Two principal mechanisms which operate for slow neutrons (below 0.05 eV) are (a) inelastic scattering where energy is transmitted from the neutron to the nuclear lattice or vice versa and is inversely proportional to the velocity of the neutron; (b) diffuse incoherent scattering which is associated with the presence of concentrations of nuclei whose nuclear spin is orientated with respect to the neutron spin. An additional factor, that of diffraction, is operative for faster neutrons (energy 0.05 eV−0.5 eV) where the wavelength is comparable with the crystal lattice spacings. This contributes the major part of the cross section for the scattering of neutrons in this energy range. This form of scattering is analogous to Bragg scattering in X-ray diffraction. Significant peaks occur in the wavelength/scatter cross section curves, when the wavelength of the neutrons is a digital function of the normal lattice spacings. As the neutron energy increases, and the wavelength becomes shorter, more and more crystal planes contribute to the scattering and for beryllium it reaches a steady value of about 6 barns at energies of 0.5 eV, and above.

The crystal size plays an important part in establishing the nuclear cross-section values for polycrystalline beryllium. This is due to the fact that the neutrons may be scattered on more than one occasion in the same crystal. The scattering cross-section for neutrons of 0.025 eV has been determined as 3 barns for "large crystals" and 6 barns for "fine crystals." In a nuclear chain reactor using beryllium this effect could possibly be quite significant as the proportion of the neutron flux below 0.5 eV can vary markedly with temperature, the most probable neutron energy at 17°C for example is 0.025 eV and this figure doubles itself for a temperature increase of about 300°C. Detailed nuclear properties are shown in Table 1 on the data sheet.

Physical Properties

Some of the important physical properties of the metal are given in Tables 3 to 7.

Crystal Structure. Beryllium has a close-packed hexagonal structure with lattice parameters $a_o = 2.281$ Å and $c_o = 3.577$ Å and a c/a ratio of 1.568 at room temperature. Recent work[8] on the melting point determination of beryllium has led to the suggestion that a transformation takes place below the melting point. Sidhu and Henry[9] also suggested that an allotropic modification existed. Other workers[10] associated this with the presence of BeO. Losano[11] working with beryllium, claimed to be of 99.96% purity suggested that a transformation may occur at 600-700°C. Ellis[12] has recently noted a change in resistivity at about this temperature which he attributes to a solution effect. The evidence for the transformation at the lower temperature is slight and the effects normally to be expected from it are not readily apparent.

The c/a ratio for beryllium varies approximately linearly with temperature being 1.568 at room temperature and 1.562 at 1,000°C (Table 2 of the data sheet).

FABRICATION

Melting and Casting

Attempts to develop a satisfactory technique for melting and casting beryllium have been made over a number of years.[13] The melting point of the metal (1,280°C) is not high and induction heating is almost universally used for production purposes.

The reactivity of the metal, together with the toxic nature of the oxide, necessitates the use of closed chambers. Normal practice is to use a vacuum tank equipped with means for the introduction of argon to a controlled pressure. Furnaces are normally designed for lip pouring, as many of the impurities, for example beryllium oxide and magnesium fluoride, are more dense than the metal, and sink to the bottom of the crucible. Cast iron is widely used as a mould material. Graphite can also be used but precautions must be taken to minimise the formation of beryllium carbide.

The selection of a suitable crucible material for containing the metal is of the utmost importance, and is made extremely difficult as beryllium metal reacts with almost

every other oxide. This is associated with the very high heat of formation of beryllium oxide and the fact that beryllium metal forms intermetallic compounds with nearly all metals. The dynamics of the beryllium metal oxide reactions can be expected to be dependent on the particular oxide considered and the conditions of melting (including pressure of gas above the melt). For example MgO, CaO and Al_2O_3 react quite slowly and the pot becomes lined with BeO which tends to reduce further action. The use of magnesium oxide is, however, undesirable as the magnesium metal liberated as vapour gives rise to difficulties, particularly during vacuum melting as it tends to condense and cause shorting across the turns of the induction coil. Graphite is unsuitable as a crucible material, as beryllium carbide forms readily at temperatures above the melting point.

Fortunately, the solubility of oxygen (BeO) in beryllium is small and BeO crucibles are therefore suitable.

The production of sound castings in beryllium is difficult, as the metal has a marked tendency to form large grains on crystallization and these grains are brittle in preferred directions. Careful attention to such factors as casting temperature, rate of teeming, and mould conditions (wall thickness and temperature) is necessary if the metal is to be both free from macro-cracking and have an acceptable grain size. It will be appreciated that the problem becomes increasingly difficult as the diameter of the ingots increases. All attempts to refine the cast grain structure and to improve the machining characteristics, by using additions of 0.1% Fe, Si, Ti, Ni,[16] as grain refining agents, have been unsuccessful. The cast grain size was not significantly different from that of pure beryllium.

There is considerable incentive to develop techniques for producing cast beryllium in a usable form as the route is far less expensive than the only alternative route available, i.e. the use of powder metallurgy. Vacuum melting is, however, used as a purification stage, and volatiles such as fluorides, chlorides, and magnesium metal can be reduced to very small levels indeed. It is important to note that no appreciable reduction of the oxide content can be expected during normal vacuum melting.

The cast metal is quite brittle and shows practically no elongation in tension at room temperatures. It is hardly conceivable that it could be used in this condition for structural purposes, unless the imposed stresses were of a very low value and compressive in nature.

The difficulties mentioned have led to the abandonment of this method for producing castings even for the manufacture of reflectors which are not subject to severe external stresses. The main application of the process at present is as an interim purification stage, particularly for metal produced by the magnesium reduction of beryllium fluoride.

POWDER METALLURGY

Powder Production

The main objective of using powder metallurgy techniques is to ensure the fine-grained structure necessary for the production of finished components having adequate mechanical strength and ductility.

The first step is clearly the production of powder having suitable sintering characteristics and two processes will be described, the first being applicable to either the flake or the fluoride metal and the second designed particularly for electrolytic flake.

Powder production from the fluoride metal commences with vacuum melting the pebbles, to give ingots which may be 9 in. diameter, weighing say 100 lb. These are machined using multiple tools to give the metal in a suitable form such as small chips which are fed into a beryllium-faced attrition mill, where they are reduced to −200 mesh powder. Particular care is taken to avoid contamination with the mill constructional materials, but an increase in oxygen content is noted, despite the fact that an atmosphere of nitrogen is maintained inside the mill.

The electrolytic process yields beryllium as a flake which is usually contaminated with the chlorides of the fused electrolyte; this chloride content may be as high as 0.14% and is undesirable for three reasons. First, the presence of this amount of chloride doubles the neutron capture cross-section and, secondly, it has an undesirable effect on the physical and mechanical properties of the sintered product. In addition, the finished beryllium components are unstable on exposure to atmosphere, and develop white excrescences. Considerable attention has been devoted to this problem in the U.K., and work by A.E.R.E. Harwell[15] in particular has led to the development of a leaching process using oxalic acid. An initial ball milling operation is necessary to reduce the flake to the required particle size in order to ensure that the leach liquor has access to the chloride. It is important to note that this technique is potentially capable of giving a product which may be very low in oxygen. The only alternative method involves melting in a BeO crucible and can only give a metal which is, at best, saturated with oxygen.

The particle size distribution is particularly important whatever the detailed route used, and exerts an important influence on both the success of subsequent fabricating processes, and the properties of the finished components.

Powder Processing

Cold Pressing and Sintering. Hausner and Pinto,[16] studied the cold pressing of beryllium and found that the minimum pressure for handling in the green state was about 15 tons/in.^{2} which gave pressings having 60% theoretical density.

With increasing pressure they found an almost linear increase to about 85% theoretical density at 70 t.s.i. and little further increase was gained at pressures up to 90 t.s.i. With decreasing particle size increasing pressures were required to attain a given density. This latter effect is to be associated with other incidental factors, such as the increased oxide content associated with the smaller particle size of powder.

The sintering of the beryllium compacts in argon and in vacuum appear to involve fundamentally different mechanisms. Vacuum sintering studies by Hausner and Pinto were made under vacua of about 10^{-5} mm Hg. The specimens were contained in beryllia boats and were heated at a standard rate up to the sintering temperature.

Standard sintering conditions, viz. a vacuum of 0.5μ, a sintering temperature of 1,200°C and a time of 3 hours were used to study the effect of cold compacting pressure upon sintered density. Under these conditions maximum density was obtained at a pressure of 55 t.s.i. However, as will be seen from Fig. 2, the effect of cold compacting pressure is quite small. Jenkins and Jones[17] confirmed this but found that compacting pressures (and sintering times) had considerable effect at lower sintering temperatures. The effect of sintering temperature on density is shown in Fig. 3. It will be seen that no densification occurs at temperatures of less than about 1,000°C for sintering times of 3 hours in vacuo.

Sintering in argon produced quite different results. The profound effect of compacting pressure up to about 60 t.s.i. is seen from Fig. 2.

The metallurgical structures of compacts after sintering in argon and in vacuum are different. The initial cold-

pressed structure consisted of flattened and fragmented spheres with the major axis of the platelets perpendicular to the pressing direction. Above about 1,000°C recrystallization and grain growth processes occurred and above about 1,100°C grain growth became pronounced in the case of specimens sintered in vacuum. Jenkins and Jones[17] report a difference of a factor of 8 in the grain size of comparable compacts after sintering in argon and vacuum. Hausner and Pinto also noted this, and found that the time of sintering had a pronounced effect on the grain size of compacts sintered in argon, whilst the effect of time was negligible when sintering was carried out in vacuum.

The physical loss of beryllium, by evaporation during vacuum sintering, was considerable at the temperatures required for the production of high-density compacts. Hausner and Pinto have suggested that this is a function of the exposed surface area of the bar, rather than the amount of beryllium involved. This agrees with the observations that losses can be reduced by embedding the compacts in BeO powder.[18]

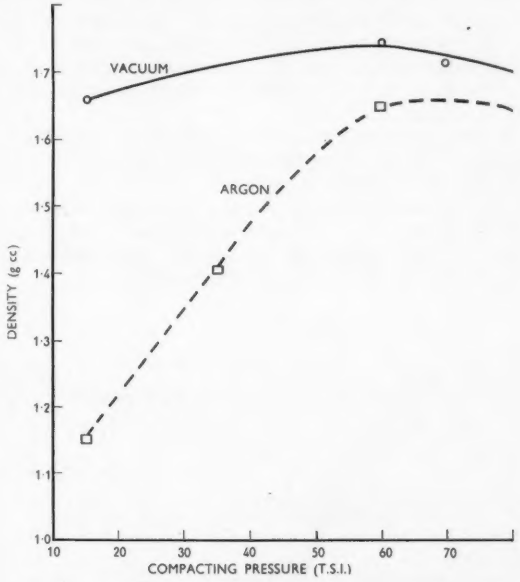

Fig. 2.—Comparison of vacuum-sintered and argon-sintered beryllium compacts after sintering for three hours at 1200°C.

[H. H. Hausner and N. P. Pinto (16)].

Pressing at Temperature. The density of compacts pressed at room temperature at pressures of 25 ton/in.^{2} for 15 min is 65% theoretical. This increases to theoretical density when the temperature of pressing is increased to 600°C.[16] Blainey and Lloyd[19] showed that the time of pressing is of considerable importance. Summarizing, therefore, in the temperature range up to 600°C pressures of 20 to 100 t.s.i. may be employed. With increasing temperature the pressures required are appreciably reduced, and the time of application of pressure becomes important.

The temperatures and pressures which can be used for production are limited by die materials available. Graphite can be used at temperatures up to 1,050°C but some protection is required to prevent the formation of beryllium carbide. At lower temperature recourse must be had to the nickel and cobalt base alloys. Nimonic and Stellite can be used under conditions which will give compacts of satisfactory density at 850°C.[15]

The problem of die materials can, to some extent, be alleviated by using a forging technique. For this, beryllium powder is placed in a mild steel can of suitable shape. The can is maintained under vacuum while it is preheated in order to outgas the powder and is then sealed off. It is then heated in an inert atmosphere to 1,000-1,150°C and forged in a closed die which is generally preheated to 3-800°C.

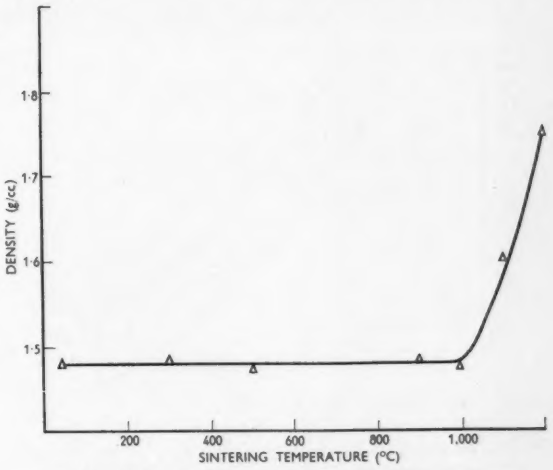

Fig. 3.—Effect of sintering temperature on density of beryllium sintered for three hours in vacuo samples compacted at 55t.s.i.

[H. H. Hausner and N. P. Pinto (16)].

Vacuum hot pressing is an alternative technique which is now widely used for producing very large blocks of beryllium. In this type of operation pressures as low as 75 p.s.i. have been used at 1,050°C.[20] Times of 1 to 20 hours are employed, depending on temperature and pressure. Without the application of a vacuum, pressures of 1,500-2,000 p.s.i. are necessary to achieve maximum density.

Vacuum hot-pressing techniques have also been carried out using pressures applied hydrostatically. For this the beryllium powder is packed into a contoured steel can which is then arranged in a suitable pressure vessel, so that argon, or other protective gases, up to about 300 p.s.i. can be applied externally and the inside of the can evacuated simultaneously. Temperatures of 1,000 to 1,100°C are generally employed.

Summarizing, several processes and combinations of processes are available for the direct compaction of the beryllium powder to finished shapes, without having recourse to the conventional mechanical working operations which will be described later. Each technique has a particular field of application and alternatives are often available for similar shapes; it is possible that the choice of process may well be decided by the plant and techniques available at a particular plant. The vacuum hot-compacting technique is widely used, and methods for producing slabs weighing many hundreds of pounds each have been developed in the United States; in this case the pressures used were in the range 50-250 p.s.i., the temperature being 1,050°C.

Mechanical Working

(a) Forging. The forging of cast beryllium for grain refinement has been attempted[21] without success. Bishop[22] discusses the die forging of beryllium fabricated from powder, and claims that quite complicated shapes can be

produced if the material is maintained in compression and not required to flow too far.

(b) Extrusion. Methods for the hot extrusion of beryllium have been successfully developed. Early work using normal techniques revealed severe die-galling problems. Refractory alloy dies reduced this problem somewhat but this factor, together with the difficulty of heating beryllium to the temperatures required (about 1,000°C) when working with large extrusion ratios (about 8 : 1 or more),

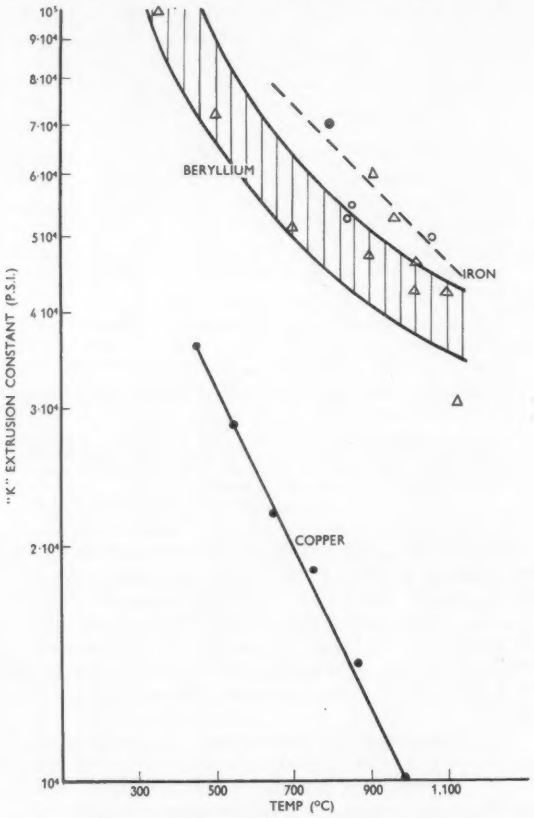

Fig. 4.—Extrusion constants of Be, Cu and Fe: temperature.
[P. Loewstein, A. R. Kaufman and S. V. Arnold (7)].

led to the cladding of the beryllium. Experiments by Creutz and Gorinsky[21] using graphite liners gave promising results. The greatest advance in this field is attributed to Kaufman,[41] who showed that cladding in mild steel is practicable and gives excellent results. This is associated with the fact that mild steel has similar extrusion characteristics to beryllium at 1,000°C and does not alloy seriously below 1,100°C. The method has proved to be an extremely successful innovation. In addition to solving the problems of die wear, and surface finish, later tests showed that it could also be used in conjunction with cold compacted powder, thus eliminating the necessity for an initial densification operation prior to canning in the mild steel. The beryllium to be extruded is packed into a seamless container of about $\frac{1}{16}$ to $\frac{1}{4}$ in. wall thickness, depending on the extrusion ratio to be employed. The leading face of the pack can be in the form of a truncated cone or may be flat with radiused corners. The rear face of the pack consists of a substantial steel plate welded to the can. Provision is generally made for evacuating the assembly through a small tube on the rear face. In the case of powder, this is compacted into the can under a pressure of about 5 to 10 t.s.i. This has two effects. First, the density of the beryllium is increased and, secondly, the buckling of the walls during extrusion is very much reduced. Steel cans with $\frac{1}{8}$ in. wall thickness are generally used for the containing of beryllium up to about 4 in. diameter.

For larger billets, a special hot-compacting technique can be employed. In this case the pack is prepared as before, using a thick-walled mild steel can and is heated to the extrusion temperature. The extrusion container with a blank die is used as the compacting chamber, and a punch of suitable size to fit into the internal diameter of the mild steel can is used. Loads of up to about 40 t.s.i. are applied. This tears the welded mild steel back plate from the container wall and moves it forward, compacting the beryllium powder in front of it. The assembly is removed from the extrusion container and allowed to cool. It is then skimmed to clean up the outer mild steel can to a size suitable for reinsertion in the extrusion press and subsequently extruded as a normal billet.

The extrusion dies used are of normal design. Die materials are generally high-speed steel with an insert of tungsten-chromium-cobalt alloy. In certain cases, cobalt-chromium alloys with case-hardened working face are used.

Fig. 4 shows the variation of the extrusion constant with temperature. This constant K, the billet pressure P and the extrusion ratio or reduction in area R are related by the expression $P = K \ln R$.

K can vary somewhat for a number of reasons, e.g. quantity and type of lubrication, and billet size. The temperature of working is generally above that for full recrystallization (about 900°C) and large reductions in area can be given. The maximum temperature used is about 1,050°C. This is as high as can be employed without serious alloying of the can and the beryllium.

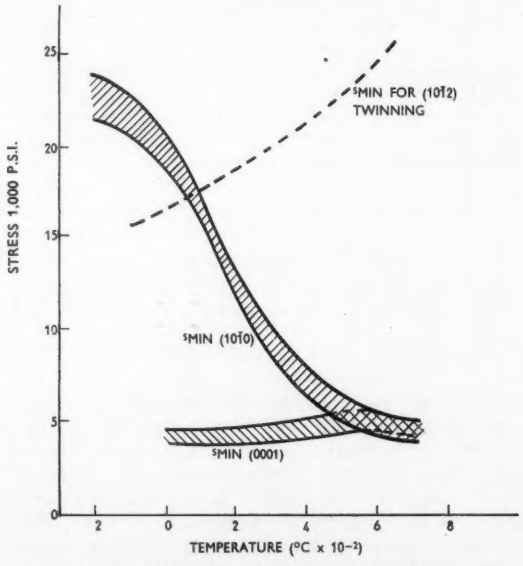

Fig. 5.—Effect of temperature on the critical stresses for (0001) slip and $(10\bar{1}0)$ slip.
[G. L. Tuer and A. R. Kaufman (5)].

Rods, tubes, flats and simple shapes can be extruded using this canning technique. Dimensional tolerances on the article after stripping are quite good. However, they are inferior both in this respect and in surface finish to those extruded using "bare" metal.

The majority of the work on bare extrusion has used temperatures of about 400°C-450°C, coinciding with the

Nuclear Engineering
DATA SHEET
No. 4 Beryllium

PROPERTIES OF BERYLLIUM
Symbol Be

A	**Atomic and Nuclear Properties**	Table 1
B	**Physical Properties**	
	1. Structural properties	Table 2
	2. Density g/cm³ (calculated from lattice constants)	1.8477 ± 0.0007
	3. Contraction on solidification	3%
	4. Thermal properties	Tables 3, 4, 5
	5. Thermodynamic properties	Table 6
	6. Electrical properties	Table 7
C	**Corrosion**	
	1. Rate of oxidation	Table 8
	2. Stress rupture strength in sodium	Table 9
D	**Mechanical Properties**	
	1. Elastic properties	Table 10
	2. Tensile and Creep properties	
	(a) Isotropic materials	Figs. 6, 7, 8, 9, 10, 11, 12
	(b) Anisotropic materials	Figs. 13, 14, 15, 16, 17
	3. Compressive properties	Table 11
	4. Hardness	Table 12
E	**Heat Treatment**	Table 13

TABLE 1
Atomic and Nuclear Properties (40)

Atomic number		Atomic weight	Electron configuration
4		9.013	$(1s)^2(2s)^2$
Isotope	**Mass**	**Packing fraction**	**Binding energy (MeV)**
Be^6	6.0219	0.00365	4.41
Be^7	7.01916	0.00274	5.33
Be^8	8.00785	0.00098	7.02
Be^9	9.01503	0.00167	6.42
Be^{10}	10.01677	0.00168	6.45
Be^{11}	11.0277	0.00252	5.69

Electron orbit	Ionization potential (Rydbergs)	Orbital radius (Å)
(1s)	9.3	0.143
(2s)	0.69	1.19

Isotope	Energy of radiation (MeV)	Half life	Method of production
Be^7	γ, 0.453–0.485	54.5 d	Li^6 (d,n) Li^7 (p,n) B^{10} (p,α) B^{10} (d,αn)
Be^8	γ, 0.055	10^{-15}–10^{-17} s	Be^9 (γ,n)
Be^9	Stable	—	Occurs in nature
Be^{10}	β, 0.56–0.65, no γ	2.7×10^6 y	Be^9 (α,p) Be^9 (n,γ) B^{10} (n,p) C^{13} (n,d)

Neutron Cross Section

Neutron energy (MeV)	Capture cross section (Barns)	Total cross section (Barns)
10^{-7}	0.009	2
10^{-6}	0.009	5
10^{-5}	0.009	6
10^{-4}	0.009	6
10^{-3}	0.009	5.3
10^{-2}	0.009	5
10^{-1}	0.009	4.5
6×10^{-1}	0.009	7
1	0.009	2.3
2	0.03	1.6
4	0.04	1.8

PHYSICAL PROPERTIES

TABLE 2
Structural Properties (40)

Crystal structure Space group	Close-packed hexagonal $D(6h)^4$		
Lattice Constants	**a, kX**	**c, kX**	**c/a**
Room Temp.	2.281	3.577	1.568
200°C	2.287	3.584	1.567
400°C	2.296	3.594	1.566
600°C	2.305	3.606	1.564
800°C	2.315	3.618	1.563
1000°C	2.325	3.632	1.562
Interatomic distances d_1			2.221 kX
Interatomic distances d_2			2.281 kX
Co-ordination number			12
Atomic radius			1.123 kX

TABLE 3
Thermal Properties

Melting Point (32)	1,283°C	
(40)	°C	Pressure
Vapour Pressure (solid)	900	10^{-8} at
Vapour Pressure (solid	1,235	10^{-5} at
Vapour Pressure (liquid)	1,950	10^{-2} at
Vapour Pressure (liquid)	2,970	1 at
Heat of fusion	259 cal/g	
Heat of vaporization	5,930 cal/g	

TABLE 4
True Coefficients of Thermal Expansion (40), $\frac{1}{x} \cdot \frac{dx}{dT} \cdot 10^6$

Temp. (°C)	Volume Coefficient	Linear Coefficient	
		Perpendicular to hexagonal axis	Parallel to hexagonal axis
60	32	12	9
100	39	15	11
200	46	17	13
300	50	18	14
500	55	20	15
700	60	21	17
900	65	23	19

TABLE 5
Thermal Conductivity, (32), **cal/cm², sec, °C**

Temp. (°C)	Sintered Powder	Extruded Flake
200	0.39	0.33
400	0.38	0.31
600	0.37	0.29

MECHANICAL PROPERTIES

TABLE 6
Thermodynamic Properties (40)

Temperature (°K)	Heat capacity Cp (cal/mole, °K)		Enthalpy, Ht–Ho°, (cal/mole)		Entropy, St, (cal/mole, °K)		Free-energy function (cal/mole, °K)	
	Condensed	Vapour	Condensed	Vapour	Condensed	Vapour	Condensed	Vapour
298.16	4.26	4.97	465	1,481	2.28±0.02	32.56±0.01	0.72	27.60
500	4.85	4.97	1,365	2,484	4.56	35.13	1.83	30.16
1,000	4.30	4.97	4,210	4,971	8.45	38.57	4.24	33.61
1,500	7.75	4.97	7,455	7,451	11.05	40.59	6.07	35.62
2,000	5.27	4.97	13,565	9,931	13.98	42.02	7.20	37.05

TABLE 7
Electrical Properties (40)

Temperature (°C)	Resistivity (μΩ/cm)	Thermoelectric Power against Pt (μV/°C)
0	4	—
200	9	—
400	15	10
600	22	14
800	32	18
Electrochemical Equivalent		0.04674 mg/coulomb
Electrolytic solution potential Be/Be^{++} ..		Eo=1.9 V
Superconductivity		Possibly below 11°K

TABLE 10
Elastic Properties (Single Crystal) (32)

Direction relative to basal plane	Young's modulus (p.s.i. x 10^{-6})	Poisson's ratio
Perpendicular	53.4±1.7	0.10±0.02
Parallel	40±2	0.035±0.01

TABLE 11
Compressive Properties (43)

Material	Treatment	Direction of Test	Ultimate Tensile Strength (p.s.i. x 10^{-3})	Yield Strength 1% offset (p.s.i. x 10^{-3})	Defo
Vac. cast	As extruded at 760°C	Longitudinal	154	—	
		Transverse	47	—	
Vac. cast	As extruded at 980°C	Longitudinal	154.5	—	
		Transverse	83.3	—	
Brush premium ..	As extruded at 1,005°C	Longitudinal	208.6	68	
Grade powder ..		Transverse	152.8	80.9	

CORROSION

TABLE 8
Rate of Oxidation at 825°C (33)

Time (min)	Wt. gain (μg/cm²)
5	6
10	10
20	15
40	22
60	29
80	35
120	44

TABLE 9
Stress Rupture Strength in Sodium at 538°C (42)

Method of Fabrication	Stress	Time to Rupture (h)	% Elong.
Hot Pressed	5,000	1,274	3.5
	7,000	858	4.2
	8,000	378	5.2
	9,000	50	
	10,000	221	
	11,000	87	
Hot Pressed warm extruded ..	2,000	955	1.8
	2,500	285	3.8
	3,000	148	0.1
Hot Pressed hot extruded ..	2,000	4,536	2
	2,500	5,724	4
	3,000	584	6
	4,000	235	4
	6,000	15	10
	10,000	4	8

N.B. Oxygen content of Beryllium not stated.

TABLE 12
Hardness of Beryllium* (40)

Temperature (°C)	Brinell Hardness Number
R.T.	106–130†
300	88
400	90
500	74
600	61
700	50
800	21
900	11
1,000	9

* Many factors affect hardness including source of metal, method of fabrication and heat treatment. The information available is not sufficient for a complete assessment of the effect of these variables and the above figures should be regarded as being indicative only.
† Dependent on source of material.

TABLE 13
Heat Treatment† (41)

Recrystallization Temperature (°C)	Time for recrystallization	
	Light Deformation (h)	Heavy Deformation (h)
725	—	10
800	5×10^{-1}	10^{-1}
900	6×10^{-3}	3×10^{-3}

† The major effect of heat treating Beryllium is associated with recrystallization and grain growth. The recrystallization temperature varies depending on the degree of deformation. Grain growth is rapid at temperatures of 900°C and above and results in material of lower strength and slightly higher ductility. Preferred orientation effects persist above 1,000°C. It can therefore be inferred that even if the preferred orientation is removable by heat treatment at temperatures above 1,000°C, then this could only be achieved at the expense of excessive grain growth.

son's ratio
10±0.02 35±0.01

ield ength offset x 10^{-3})	Deformation %
—	13.0
—	3.7
—	18.3
—	9.2
8	31.5
0.9	10.4

rmation (h)
0 $^{-1}$ 10^{-3}

crystallization
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Fig. 6.—Eleva
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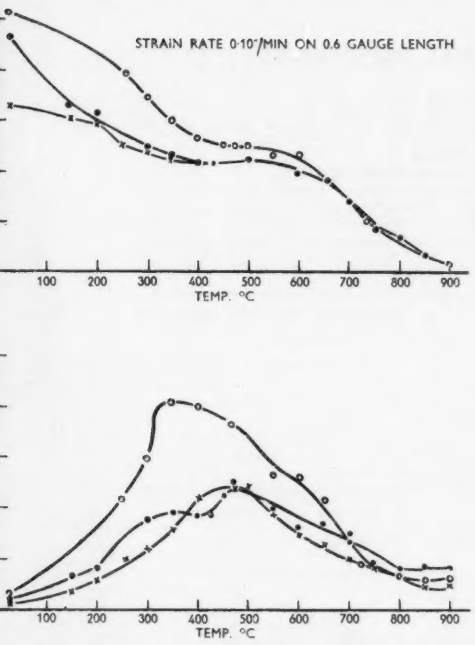
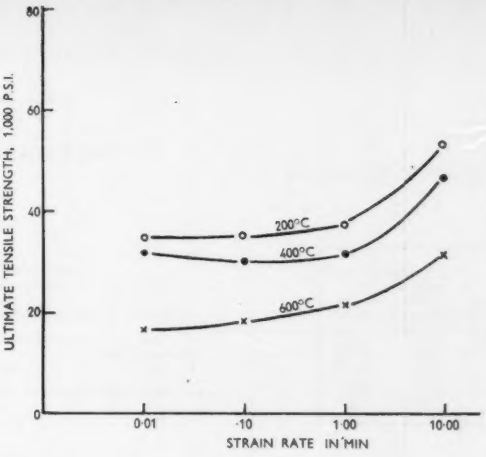


Fig. 6.—Elevated temperature tensile properties for three lots of vacuum hot pressed Q.M.V. Beryllium.
[W. W. Beaver and K. G. Wikle (30)]



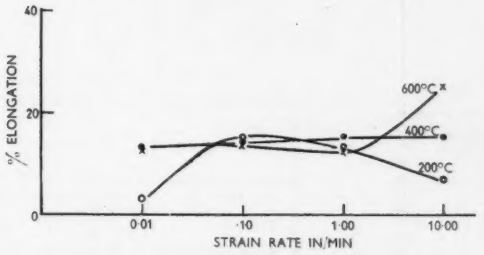
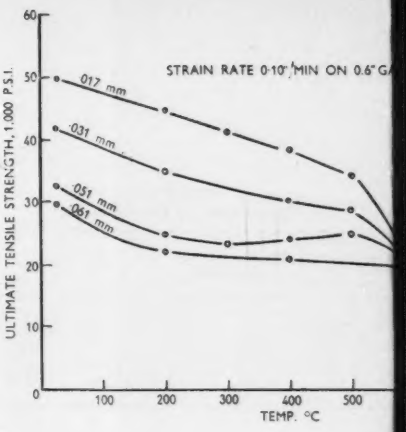


Fig. 7.—Effect of strain rate on the elevated temperature tensile properties of vacuum hot pressed Beryllium.
[W. W. Beaver and K. G. Wikle 30)]



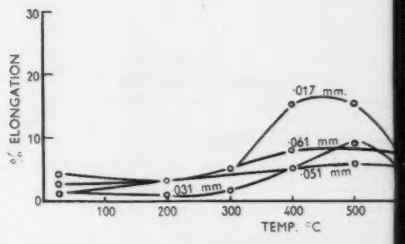


Fig. 8.—Effect of grain size on the tensile
vacuum hot pressed Q.M.V. Beryllium
[W. W. Beaver a

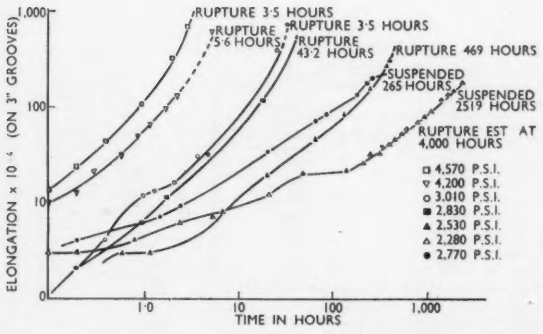
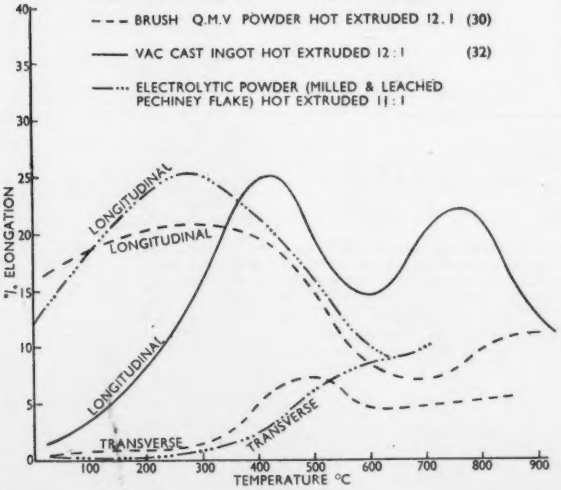


Fig. 12.—(Above) Creep curves at 650°C for vacuum hot pressed Q.M.V. Beryllium powder (1% BeO).
[R. G. O'Rourke, J. N. Hurd, K. G. Wikle, W. W. Beaver (31)]

Fig. 14.—(Below) Longitudinal and transverse elongation of hot extruded Beryllium at various temperatures.



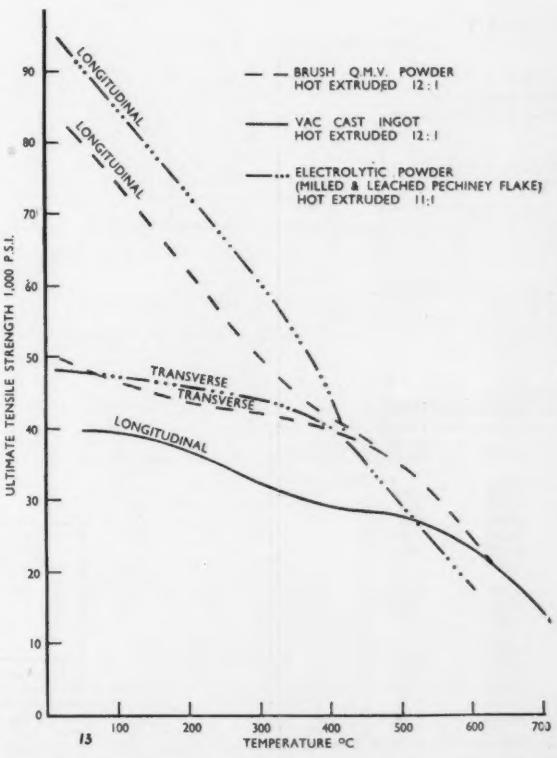
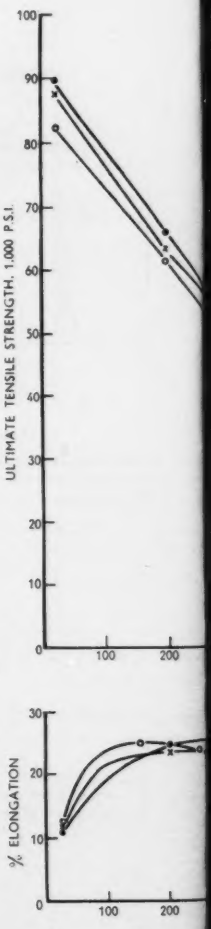
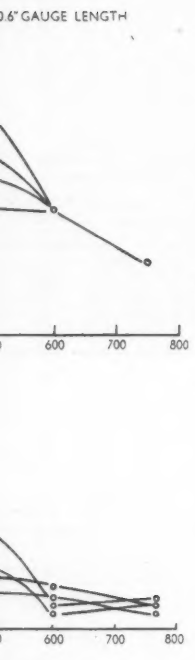


Fig. 13.—Ultimate tensile strength of hot extruded Beryllium at various temperatures.
(30, 32)





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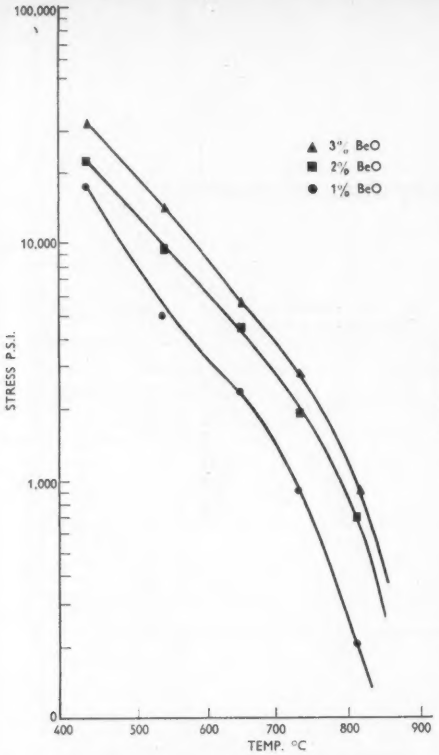


Fig. 9.—100 hour stress-rupture values against temperature for vacuum hot pressed Beryllium containing 1%, 2% and 3% BeO.
[*R. G. O'Rourke, J. N. Hurd, K. G. Wikle, W. W. Beaver (31)*]

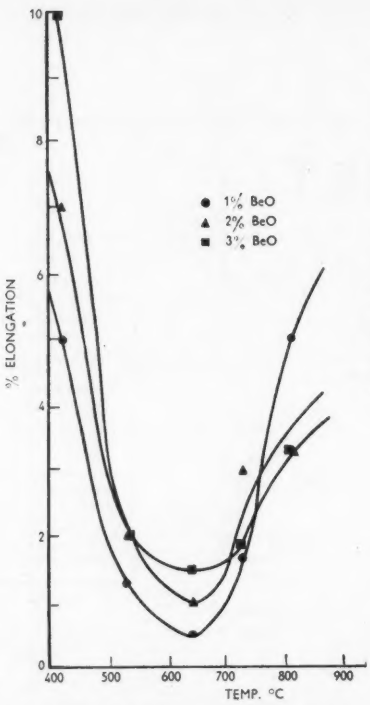


Fig. 10.—Percentage elongation at rupture for 100 hour rupture tests on vacuum hot pressed Beryllium blocks containing 1%, 2% and 3% BeO.
[*R. G. O'Rourke, J. N. Hurd, K. G. Wikle, W. W. Beaver (31)*]

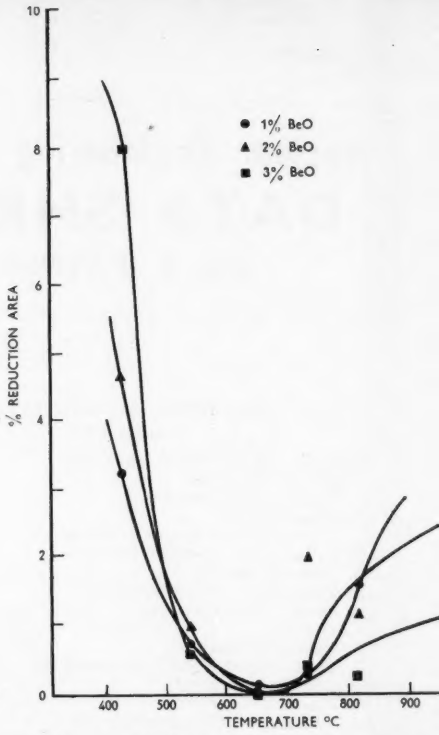
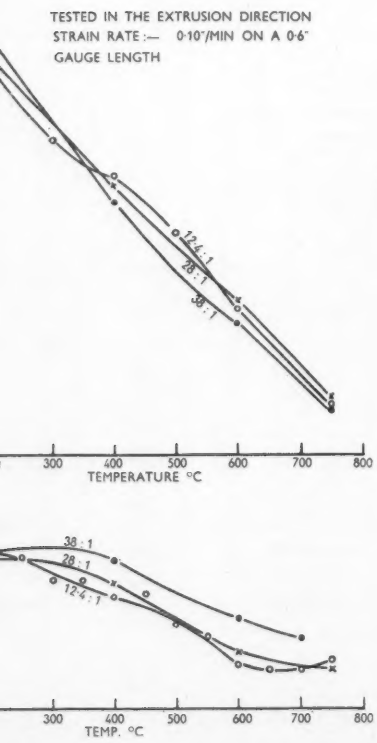


Fig. 11.—Percentage reduction in area at rupture
100 hours rupture tests on vacuum hot pre
Beryllium blocks containing 1%, 2% and 3% B
[*R. G. O'Rourke, J. N. Hurd, K. G. Wikle, W. W. Beaver,*

Fig. 15.—Effect of extrusion ratio on the elevated temperature tensile properties of hot extruded Beryllium.
[*W. W. Beaver and K. G. Wikle (30)*]



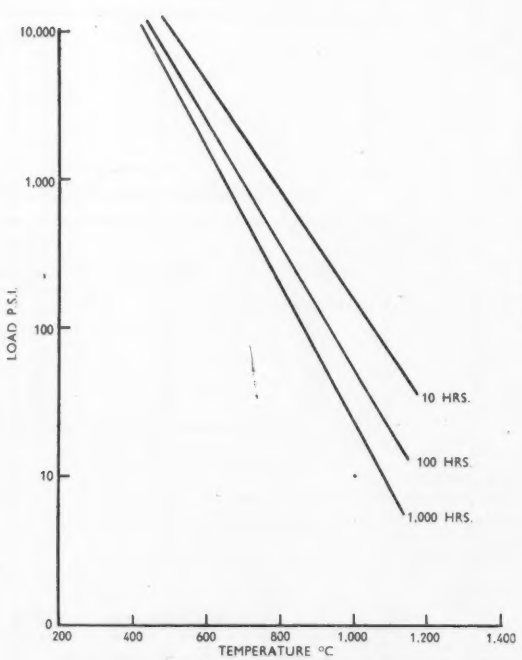


Fig. 16.—Loads to produce rupture of vacuum cast and hot extruded Beryllium in rupture times of 10, 100 and 1,000 hours at various temperatures.
[*D. W. Lillie (32)*]

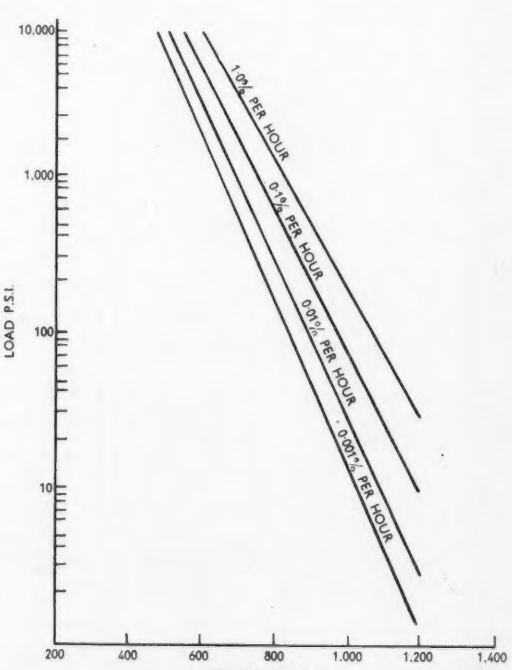
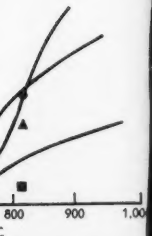


Fig. 17.—Loads to produce creep rates of 1.0, 0.1, 0.01 and 0.001 per cent per hour at various temperatures in vacuum cast and hot extruded Beryllium.
[*D. W. Lillie (32)*]



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W. W. Beaver, (31)]

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ductility peak for beryllium, and a heated die and container are normally used. Tool pressures drastically limit the extrusion ratios which can be achieved, and these two factors tend to limit the usefulness of bare extrusion to the quantity production of finished shapes from stock produced in some other way, e.g. by an initial hot extrusion in the steel-cladding technique.

(c) Rolling. Rolling techniques have become fairly well defined. The beryllium is normally clad in mild steel although for special surface finishes, stainless steel, molybdenum or copper cans may be used.

The rolling is carried out at temperatures in the range 800°C-1,100°C and total reductions as high as 95% have been achieved using reductions of 5% to 20% per pass and reheating between each pass. Finishing passes are often done at 350°C-400°C. This has the advantages of improving surface finish and of decreasing the sticking of the beryllium to its mild steel jacket.

Joining

(a) Fusion Welding. The fusion welding of beryllium is at present not an attractive process. American work on this has not given promising results mainly due to weld cracking.[23]

(b) Solid phase Welding. Martin (loc. cit.) quotes time-temperature requirements for solid phase welding of beryllium in argon atmospheres or in vacuum. This work was carried out at temperatures of 900°C-1,250°C with times of 1-24 hours. Pressures are not given, but it can be expected that these are of the order of 10-1,000 p.s.i.

Williams[24] and Ellis[25] have shown that solid phase welding can occur at much lower temperatures with higher pressures, in a variety of atmospheres.

(c) Brazing. Brazing processes using beryllium aluminium, aluminium-silver alloys, silver, and silver-copper eutectic alloys have been used to join beryllium components. The last two can be used to join beryllium to other metals such as nickel, stainless steel, and copper. Special rapid heating techniques are necessary to limit both the diffusion of beryllium into the braze metal—and the formation of brittle intermetallic compounds.

Machining

The problems of machining beryllium are those normally associated with the machining of any brittle material. A wide range of cutting speeds, feeds and depths of cut are possible in the various machining operations. Duvan[26] suggests that as a general rule conditions which are suitable for cast iron can also be used for machining beryllium.

The extensive shrouding and extreme operator care necessary when machining without cutting fluids results in a decreased throughput when the operations are compared with the cutting of other brittle metals where these precautions are not necessary.

Wet machining methods using cutting fluids or light engine oil are attractive as they curtail or eliminate the creation of airborne dust. However, with large throughputs the reduction in value of the beryllium swarf resulting from the necessity of subsequent cleaning operations prior to recovery must be considered. A further possible disadvantage of machining wet, particularly with cutting fluid, is that a suspension of beryllium in fluid can escape over the machine and its surroundings unless extreme operator care is maintained. This if it dries out could give rise to airborne beryllium dust.

Either high-speed steel or carbide-tipped tools can be used. The rate of wear on the former is high.

Effect of Mechanical Working on Structure

The structures obtained after extrusion and rolling and combinations of these processes have been determined by J. L. Klein et al.[27] During extrusion and unidirectional rolling, orientation of the crystals occur in which the basal planes are aligned parallel to the working direction, and the C-axis at an angle of 75° to the surface of the product. A high degree of orientation was noted using extrusion ratios of about 15 : 1.

The cross rolling of extruded flats was found to result in rotation in the vertical plane in the rolling direction of the C-axes perpendicular to the sheet surface, i.e. the alignment of basal planes parallel to the surface of the sheet. Depending on the temperature this condition is achieved after a rolling reduction of between 6 and 10 : 1 in the case of powder material and about 3 : 1 for cast material. Further cross rolling causes the rotation of the C-axis to an angle of 75° to the sheet surface in the plane at right angles to the rolling direction, again with the basal planes remaining parallel to the rolling direction.

Single crystals have been used to elucidate many of the anomalies initially encountered.[28,29] Fig. 5 shows the variation with temperature of the critical minimum applied shear stresses for slip on the basal planes (0001) and on prism planes $\{10\bar{1}0\}$ the operative slip planes at temperatures up to 500°C. Also shown is the stress for twinning on the $10\bar{1}2$ plane. Very small amounts of slip on the 0001 planes { and twinning on the $10\bar{1}2$ planes } result in kink band formation and fracture rapidly occurs by crack propagation from these bands.

Polycrystalline aggregates in which the crystals are orientated in preferred directions show considerable room temperature ductility when tested in preferred directions. Thus in the case where the basal plane is parallel to the tension axis the only operative mode of deformation is $\{10\bar{1}0\}$ slip. This will permit elongations of 15% to 20%. In special cases of this orientation where additionally, the C-axes are parallel to one another, the only mode of deformation in tension is again $\{10\bar{1}0\}$ slip in a direction parallel to the basal planes. Increased perfection of orientation appears to increase the ductility by reducing the effects of localized deformation on differently orientated crystals. Elongations of 40% have been claimed for beryllium sheet in which the basal planes are parallel to the surface of the sheet.

It will be appreciated that test results and properties are difficult to interpret without a clear indication of the history of the test piece.

MECHANICAL PROPERTIES

(a) Isotropic Materials. The mechanical properties of cast material are of little interest as the ductility of this material is considerably inferior to metal produced by powder metallurgical techniques.

The mechanical properties of beryllium fabricated by powder metallurgical techniques have been reported extensively by Beaver and Wikle.[30] They used Brush QMV powder, that is, powder obtained by the vacuum melting technique discussed previously for pebble produced by the magnesium reduction of the fluoride. They report results of tensile tests at various temperatures up to 750°C and show the effect of strain rate and grain size on these

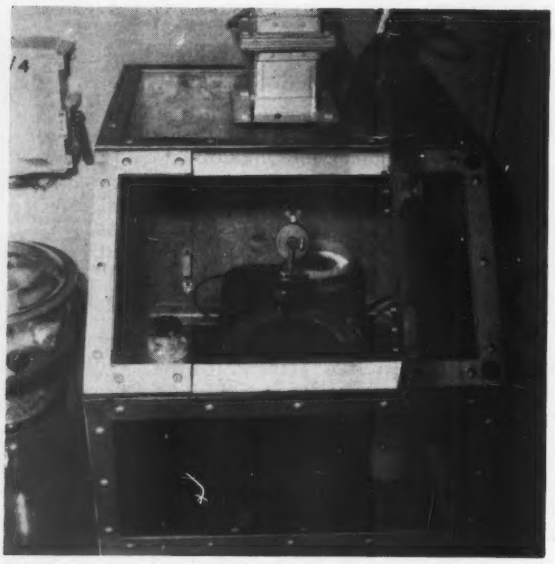

Fig. 18.—Enclosure of a polishing wheel in an air-extraction hood.

properties. These are shown in Figs. 6, 7 and 8. O'Rourke, Hurd, Wikle and Beaver[31] give further data. Figs. 9, 10 and 11 give their results for 100-hour stress rupture tests on beryllium containing 1%, 2%, 3% BeO; 1% is the normal level of BeO in powder. Fig. 12 shows creep data for vacuum hot-pressed beryllium containing 1% BeO.

Anisotropic Material. Figs. 13 and 14 show the tensile strengths and elongations respectively at various temperatures for hot extruded beryllium powder produced via both the thermal and electrolytic reduction routes; also shown are the values for cast and hot extruded beryllium. The effect of variations in extrusion ratio on the values for thermally reduced powder are shown in Fig. 15. From Fig. 14 it will be seen that two ductility peaks occur for extruded materials tested in the direction of extrusion. This is supported by evidence from torsion tests on cast and extruded rod.[32] The creep data for cast and extruded material are given in Figs. 16 and 17.

The extent to which mechanical working can modify the properties of beryllium can be clearly seen, from the above results. The improved ductility in one preferred direction is gained at the expense of this property in one or both of the other directions. This type of material is made use of for specific structural duties where the directional properties can be readily utilized to advantage. The great advantage of the materials prepared by powder metallurgical techniques is their isotropic nature. For certain applications where multi-directional stresses are likely to be encountered this material will be more suitable, particularly where accommodation of stresses by yielding is required during service.

COMPATIBILITY

With Air. The rate of oxidation of beryllium in air has been measured at various temperatures. The extremely low rate at room temperatures is associated with the formation of BeO in compression on the surface of the metal. Gulbransen and Andrews[33] found that a modified parabolic rate law applied between 300 and 950°C. Table 8 shows the data obtained at 850°C. Scales containing about 0.75% Be_3N_2 were quoted by English[34] in short-term tests at 1,000°C.

Hydrogen. There is no evidence available for the formation of a hydride. Appreciable quantities are absorbed. Rates of diffusion are not known.

Carbon Dioxide. The compatibility of beryllium with CO_2 has been studied by Williams[35] with particular reference to the possibilities of its use in thermal reactors. He

La Métallurgie du Béryllium

L'article donne des détails sur la métallurgie du béryllium en se référant particulièrement à la possibilité d'applications au domaine de l'énergie nucléaire. Les deux procédés commerciaux principaux pour l'extraction du métal y sont décrits, et on y donne une étude des méthodes de fabrication les plus importantes, ainsi que des détails des propriétés physiques et mécaniques du métal. L'influence de la structure cristalline hexagonale du métal sur ses propriétés mécaniques est passée en revue, et on suggère que la faible ductilité pourrait être associée tant avec la structure cristalline qu'avec la présence d'impuretés. On se réfère aussi à la toxicité du métal et de ses composés et à l'influence de ce danger sur la conception de l'équipment. La conclusion est tirée que les trois facteurs qui ont influé contre une plus grande application du métal dans le domaine nucléaire sont sa faible ductilité, le danger de toxicité, et le prix élevé. Le premier de ces trois facteurs (la ductilité) soulève des problèmes chimiques et métallurgiques considérables, et assurera un champ immense d'efforts dans les années qui vont suivre.

Die Metallurgie des Berylliums

Der Artikel befasst sich eingehend mit der Metallurgie des Berylliums unter besonderer Berücksichtigung der Möglichkeiten für Anwendung auf dem Gebiet der Kernenergie. Die Autoren beschreibt die beiden hauptsächlichen technischen Gewinnungsverfahren und geben einen Uberblick über die wichtigeren Verarbeitungsmethoden, sowie Einzelheiten der physikalischen und mechanischen Eigenschaften des Metalls. Der Einfluss der hexagonalen Kristallstruktur des Metalls auf die mechanischen Eigenschaften wird erörtert und die Ansicht vertreten, dass die geringe Geschmeidigkeit mit dem Kristallaufbau und der Anwesenheit von Unreinigkeiten zusammenhängt. Es wird ausserdem auf die Giftigkeit des Metalls und seiner Verbindungen und die Auswirkung dieser gefährlichen Eigenschaft für Konstruktionsteile daraus hingewiesen. Die Autoren kommt zu dem Schluss, dass folgende Faktoren einer weitgehenderen Verwendung dieses Metalls in der Technik der Kernenergie entgegenstehen: geringe Geschmeidigkeit, Giftigkeit, hoher Preis. Der erste Faktor, die geringe Geschmeidigkeit, stellt ein sehr ernstes chemisches und metallurgisches Problem dar, das in den kommenden Jahren intensiv erforscht werden muss.

La Metalurgia de Berilio

El artículo trata en detalle de la metalurgia del berilio, con particular referencia a la posibilidad de aplicaciones en el campo de energía nuclear. Los dos principales procedimientos comerciales para la extracción del metal se describen, y se hace un estudio de los más importantes métodos de fabricación, dándose detalles de las propiedades físicas y mecánicas de dicho metal. Se considera la influencia de la estructura hexagonal cristalina del metal sobre sus propiedades mecánicas, y se sugiere que la ductilidad pobre puede estar asociada tanto con la estructura cristalina como con la presencia de impurezas. También se hace referencia a la toxicidad del metal y de sus compuestos y a la influencia de este riesgo en el diseño de equipo. Se concluye que los tres factores que hasta ahora han mitigado contra una aplicación nuclear más extensa del metal son su ductilidad pobre, el riesgo tóxico y el elevado precio. El primero de éstos — la ductilidad — presenta un formidable problema químico y metalúrgico y ofrecerá un vasto campo de investigación durante los años venideros inmediatos.

concludes that at 500°C the corrosion rate in both wet and dry gas is negligible; at 600°C the corrosion film is protective in the dry but not in the wet gas; at 650°C and 700°C the surface film is no longer protective even in the dry gas. Comparisons of the weight gains in dry oxygen and carbon dioxide suggest that the change in the characteristics of

Fig. 19.—Milling machine enclosed in work hood with air extraction near the work point.

the surface film may be associated with carbide formation in the latter case.

Water. Poor corrosion resistance of extruded beryllium to water at 270°C was reported by English. Pronounced pitting effects were found at this temperature. Other workers have found that at temperatures up to about 300°C beryllium had good corrosion resistance in pure distilled water. The tendency to localized corrosion at carbide, inclusion or other sites was found to be enhanced by the presence of chloride, sulphate, iron and copper ions. Stress corrosion cracking was not noted.

Liquid Metals. Koenig[36] reports work on corrosion tests in a number of liquid metals.

In sodium containing 0.003% to 0.01% oxygen, beryllium was found to be completely resistant to attack at 500°C.

No stress corrosion effects or intergranular penetration was found at 540°C in times of 4 to 5,000 hr. and with stresses of 2,000 to 11,000 p.s.i.

In lithium, beryllium was unattacked at 600° C after seven day tests.

Good corrosion resistance is reported at 600°C in bismuth, bismuth-lead alloys, bismuth-lead-tin alloys, mercury and lead.

Solids: Uranium. Williams[37] in work on massive beryllium and uranium was unable to detect any U Be_{13} at the interface after 150 hours at 620°C. This is attributed to the presence of a beryllia diffusion barrier. Further tests made using powder compacts of the mixed metals showed that volume expansion occurred during sintering at 600° C. These expansions were associated with the formation of U Be_{13}. Massive uranium and beryllium thus

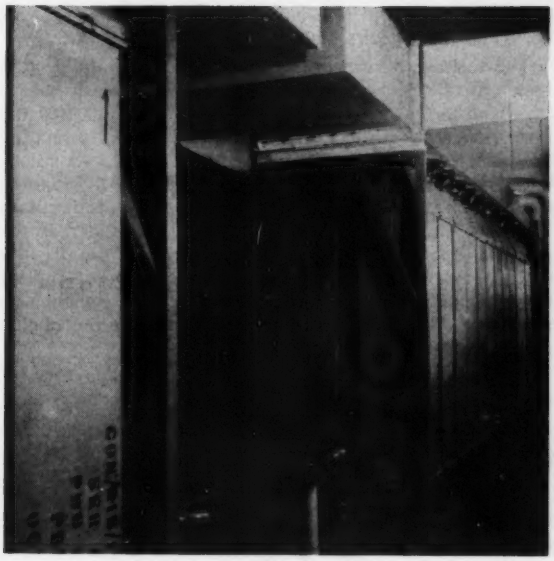

Fig. 20.—Bank of filters on the exhaust side of the ventilation system.

appear to be compatible under the above conditions at temperatures up to 600°C. However, at the higher temperatures this may be critically dependent on time and temperature. Williams' work shows clearly that the formation of U Be_{13} could be rapid if the diffusion barrier of BeO were to break down.

Other Metals. Williams has discussed work on binary alloy systems in which he observed volume expansions with a number of metals. From this work he deduced that the resulting diffusional porosity would make most brazing metals unsuitable for operation at elevated temperatures.

TOXICITY

Effects. The toxic effects arising from beryllium and its compounds have been recognized since the early 1940s. The most serious effects arise from inhalation of beryllium or its compounds. No clear evidence is available as to which forms are the most hazardous and which forms of beryllium, if any, are not dangerous. The metal, sulphate, fluoride, hydroxide, and the chloride have all given rise to berylliosis.

Skin effects occur which are less hazardous. The skin is irritated by contact with soluble beryllium compounds and dermatitis can result. Penetration of the skin by beryllium or its compounds can give rise to ulcers until the beryllium is removed.

Prevention of Beryllium Poisoning. In 1949 the U.S. Atomic Energy Commission recommended that the following exposures to beryllium should not be exceeded.[38]

1. The " in plant " concentration of beryllium in the air should not exceed 2 micrograms per cubic metre as an average concentration throughout an 8-hour day.
2. Even within the above daily average no personnel should be subjected at any time to a concentration exceeding 25 micrograms per cubic metre of air.
3. The monthly average of beryllium in the neighbourhood of any beryllium plant should not exceed 0.01 micrograms per cubic metre.

These recommendations have been considered yearly in the light of fresh information but no modification has been

made. They form the basis for safety standards for beryllium laboratories and operators.

The tolerances quoted are very low indeed, and require that all operations involving the slightest dust hazard involving the metal or its components must be carried out under strictly controlled conditions. Two main techniques are used, viz., high-velocity extraction at very dusty points, and low-velocity extraction in conjunction with enclosed hoods. The design of hoods for safe operation is discussed by Pinto.[39] He reports the linear velocities across the working apertures which are necessary for the various kinds of operation. In extreme cases, e.g. where handling large quantities of powder, full glove box handling is necessary. The air extraction system must be thoroughly filtered before being vented to atmosphere.

The design of two typical hoods are shown in Figs. 18 and 19.

Conclusions

The extremely attractive nuclear properties of beryllium have hitherto been offset by three factors, first the high price of the metal, secondly handling difficulties associated with its toxicity and, thirdly, the poor ductility.

Recent large orders for the metal placed by the U.S.A.E.C. have been placed at a price (cast metal) equivalent to that paid a few years ago for the ore alone. Further expansions in its application would certainly result in further reductions in price, although such decreases would gradually tend towards a fixed level.

It is inevitable that the toxicity hazard, and the associated necessity for protection, will play a large part in determining the detailed process used for both extraction and fabrication. However, operational standards are available, and the air sampling and associated analytical techniques required to ensure satisfactory working conditions have reached a high standard of perfection. Great care will always be necessary in planning all operations, particularly those involving the processing of metal in powder form. However, there is no reason why this should limit either the type or scale of operations providing that the plant is designed with a view to operations on beryllium.

Intensive research during the past few years has revealed that beryllium as we know it today is one of the most difficult of all metals to fabricate. This is in part due to its crystal structure, but may also be associated with the presence of impurities. The requirement for producing metal containing less metallic and non-metallic impurities is unquestionable. However, it seems unlikely that metal of appreciably higher purity can be expected from the present production routes, although the electrolytic process would seem to be inherently more capable of improvement from the point of view of metallic impurities; additionally, the electrolytic route, if associated with grinding and leaching, would seem to be potentially capable of producing metal of lower oxygen content. This is because the fluoride processing is associated with a subsequent melting operation in a BeO crucible. However, the full advantage of reducing the oxygen content is unlikely to be realized until the beryllium oxide can be reduced to a figure below the solubility of oxygen in the metal. It may well be that in this respect beryllium is as sensitive as molybdenum, where it is known that the mechanical working properties are (for arc-cast metal) sensitive to oxygen levels as low as 0.001% wt. If this is so, then we shall need to adopt a completely new approach to deoxidation techniques in order to ensure metal of the required quality. It seems reasonably certain that these 0.001% wt. 0_2 levels could not be achieved for beryllium using the conventional methods described in this article.

From the point of view of the reactor design engineers the immediate emphasis must therefore be to use to the best advantage the limited ductility of the metal as we know it today.

Its successful application for reflectors and moderators is worthy of note and it is being actively investigated as a canning metal. The mechanical properties of the metal at the very high temperatures required for direct gas turbine operation leave much to be desired, but the prospects of being able to apply metal of the quality available today for thermal reactors are good, and would, if successful, enable a marked increase in the operational temperature of such reactors to be attained.

The importance of such applications to us in the United Kingdom cannot be over-estimated, and it is certain that beryllium metal will provide an immense field of endeavour to chemists, metallurgists and engineers alike, in the years immediately ahead.

Acknowledgment

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NRU Operating

Construction Completed at Chalk River

The following account of Atomic Energy of Canada Limited's NRU reactor is based on a series of lectures given at Chalk River in 1956, and recently made generally available, and on a paper given by G. C. Laurence before the American Nuclear Society on October 30, 1957.

UNLIKE most other testing reactors, NRU is a high-flux materials-testing reactor which although utilizing heavy water as the moderator is fuelled with natural uranium. The use of natural uranium has, of course, resulted in a reactor of considerable size to obtain the required flux density (2.5×10^{14} n/cm^2-sec)* and the heat output is approximately 200 MW.

In addition to its size, NRU has many features of special interest. It is intended for plutonium and isotope production in addition to testing, and has two completely separate and self-contained charge-discharge or handling flask units, one of which is used for fuel elements or "X-rods," as they are termed, only and one for the loading and unloading of the isotope or "J-rods." Another unusual feature is that it incorporates provision for changing the "calandria" or main core vessel if required at some future date, and a calandria room has been incorporated immediately underneath the reactor.

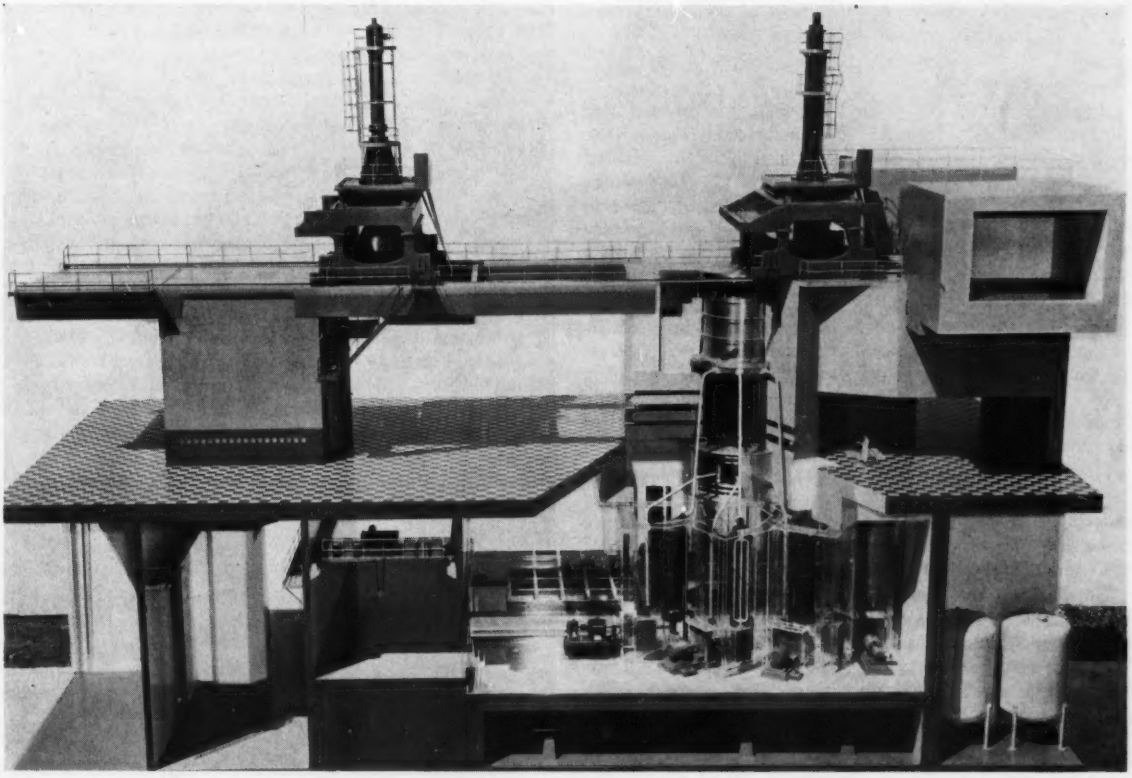
The general arrangement of the complete plant can be seen from the accompanying illustrations, showing a sectioned model and the North-South and East-West cross-sections of the building, which is approximately 150 ft long and 100 ft wide.

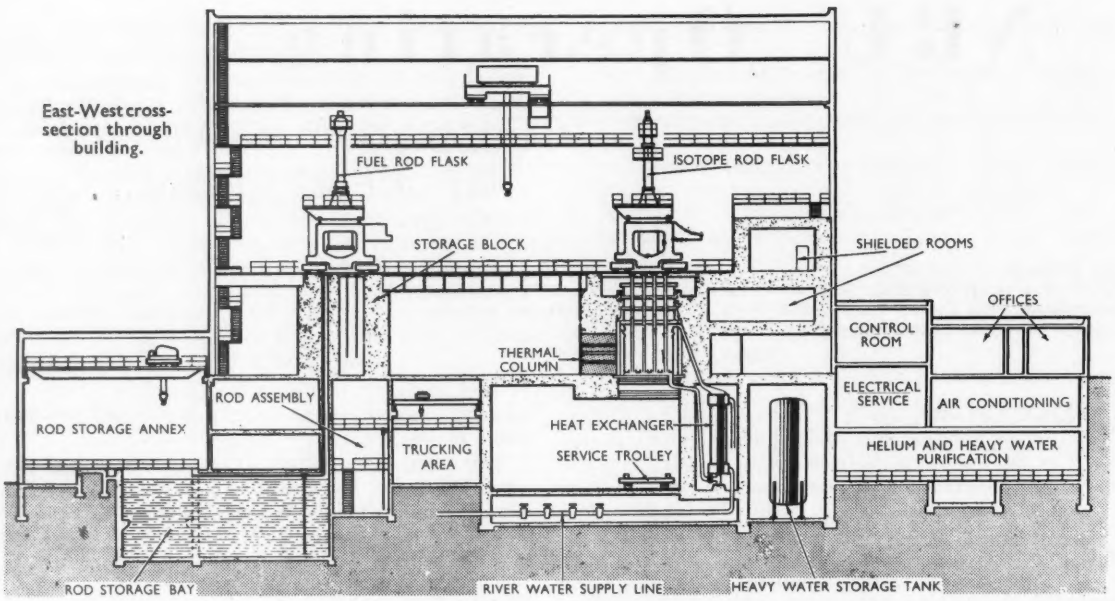
Reactor Unit

The heart of the reactor is an aluminium calandria vessel which contains the fuel rods and through which the heavy water circulates for cooling purposes, being itself cooled in heat exchangers surrounding the reactor at basement level. Outside the core vessel, there is an annular space about 6 in. wide in which the J-rods are located; this space is filled with CO_2. Outside this again is a light-

* Laurence gives a figure of 3 instead of 2.5.

Sectioned model of NRU.





water reflector in an annular tank of aluminium, while outside this is the steel thermal shielding and the concrete biological shielding.

The experimental facilities include a large thermal column in addition to through loops and horizontal and vertical experimental facilities, and the portion of the J-rod annulus opposite the thermal column is occupied by rows of bismuth rods or " B-rods " to reduce the gamma flux in the thermal column. Above the reactor vessel is a steel shield divided into three compartments, familiarly known as " boiler sections," cooled by light water.

Reactor Construction

Although there is, at present, no intention of operating the reactor under pressure, it is considered possible that, at some future date, a different calandria might be used operating up to 75 p.s.i., and the general structure of the reactor has been designed on this basis. Since this assumes that the loading on the base of the reactor will be some 500 tons and there is a free space underneath the unit for a calandria changing room, the design of the supporting structure is by no means simple.

The lower support or base ring is a heavy box section whose outer shape is like a D with the flat side located on the East side of the reactor, thus spanning the calandria room. Grooves at the top and bottom of the base ring support the two bottom shields by means of arc-shaped keys about 4 ft long.

The lower bottom shield consists of alternate layers of steel plate and masonite. The space between the lower and upper bottom shields constitutes the bottom service space and curbs and drains are provided to take care of any leakage from piping in this space.

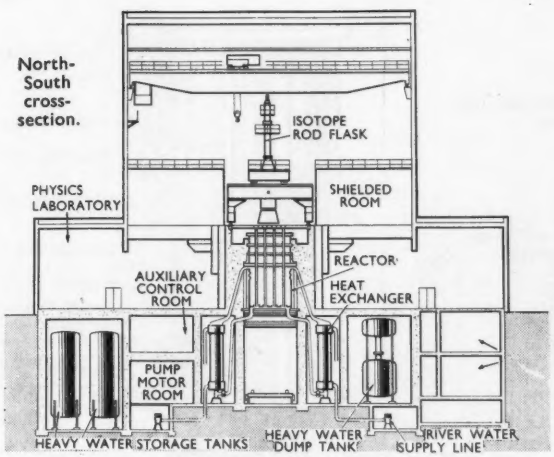
The basis of the upper bottom shield is a steel casting resembling a flywheel with a hub, deep rim, and radial ribs between the hub and the rim. Between these spokes, triangular pieces of 5-in. steel plate have been welded thus forming, in effect, a double plate, the internal space containing water for cooling. Through-sleeves are provided to enable the heavy water inlet pipes, experimental holes, J-rod thimbles, etc., to pass right through the shield and the included water space, and enter the bottom header of the reactor vessel.

Calandria

The main reactor vessel, or calandria, is in three separate portions, the shell, which is of aluminium, and the top and bottom headers or core plates, which are of stainless steel. The bottom header, which receives the cooled heavy water and distributes it to the core, is provided on its lower face with ten 10-in. pipes for the entry of heavy water and, on its upper face with cups or bushings to receive the lower end of the fuel rods. A heavy stainless-steel heat baffle is provided on top of the header.

Central location of the header is accomplished by a pipe or thimble at its centre which passes down through the centre of the shield; a key near the periphery prevents rotation while allowing radial expansion. The contact area between the underside of the header and the shield on which it rests is reduced by a series of concentric grooves.

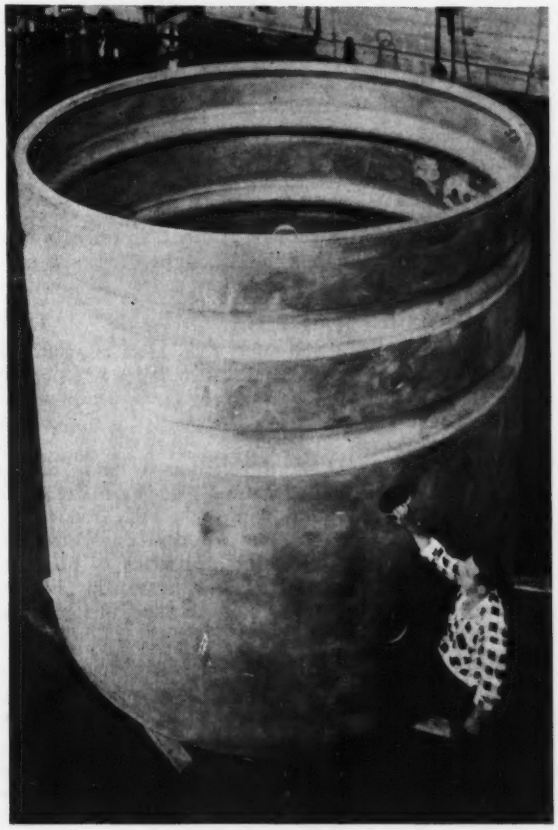
Bearing in mind the difference between the expansion coefficients of stainless steel and aluminium, and the impossibility of utilizing conventional gasket materials, it can well be imagined that the joint between the shell and the headers set some very pretty problems. The design adopted utilizes concentric rings, the outer being a $\frac{1}{4}$-in. stainless-steel tube and the inner a soft aluminium hoop of rectangular section welded to the inner diameter of the aluminium shell flange. Since any clearance in the joint would permit of movement, a tapered spigot joint was used with an interference fit of between 0.000 and 0.004 in. —no mean achievement on a vessel of this size. The top header consists of a double-tube plate which is supported, not by the vessel, but by the fuel-element guide tubes. There are 227 of these, in stainless steel $4\frac{1}{8}$ in. i.d., which extend right from the upper header to the upper service space of the reactor, and are continued from here to deck-plate level by a 3-ft " stump." The tubes are expanded into both tube plates of the top header and, in addition, are seal-welded to the lower sheet. Provision is made between the two tube plates for leakage detection. Volute-type collectors around the top plate remove the hot heavy water to the heat exchangers.

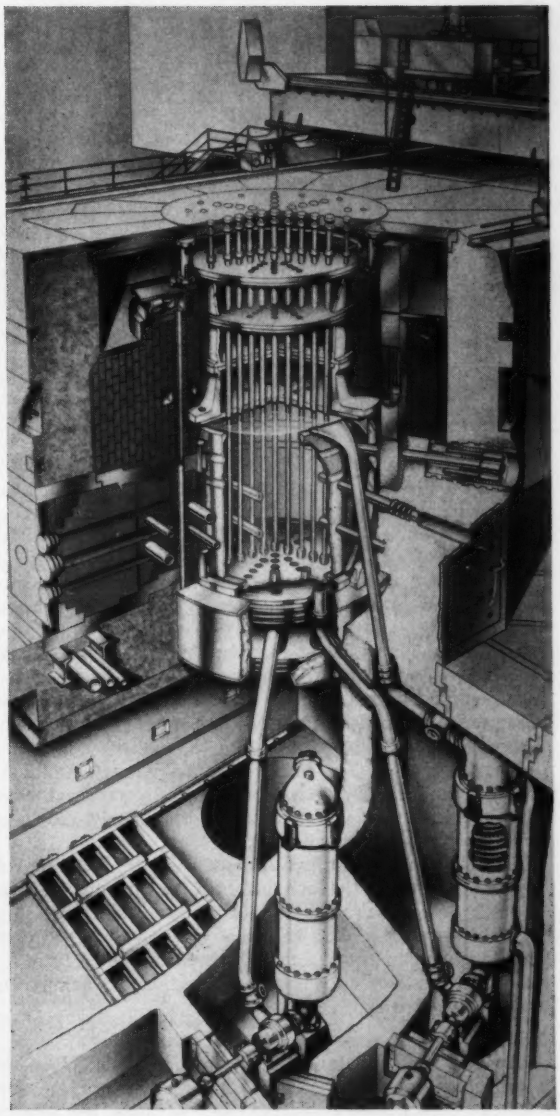


The main structural element for the top of the reactor is the bottom boiler section, which is itself supported by three columns from the base ring at the bottom of the reactor.

All three boiler sections are basically similar in that each of them is a drum-shaped fabrication consisting of a cylindrical shell with tube plates at each end, to which tubes or sleeves are welded. Each boiler section contains about 500 tubes for the fuel rods, J-rods, B-rods, etc.

On top of the boiler section is a 6-in. plate known as the master plate. Above this is the top service space and, finally, the deck plate 18 in. thick, stepped into a ring supported by columns from six brackets on the upper boiler unit. The total shielding provided above the reactor





(Above) Sectional drawing of the reactor. (Left) The aluminium calandria.

amounts to nearly 2 ft of steel and some 9 ft 6 in. of water.

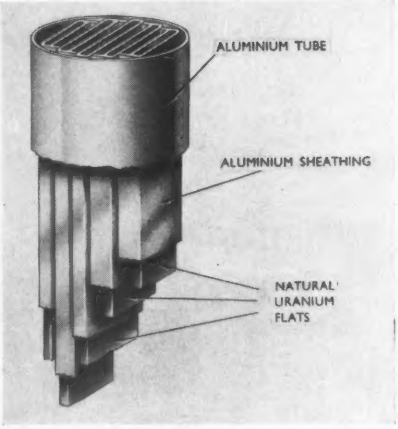
Side shielding is provided by a thermal shield 12 in. thick of cast steel, water cooled, and 9 ft 6 in. of high-density concrete using ilmenite ore and magnetite sand, giving a final density of about 220 lb/ft^3.

Core

Of the 227 holes in the headers and boiler sections six are plugged, since they are directly in the path of the thimbles for some of the horizontal experimental facilities. The number of fuel elements is stated to be 201.†

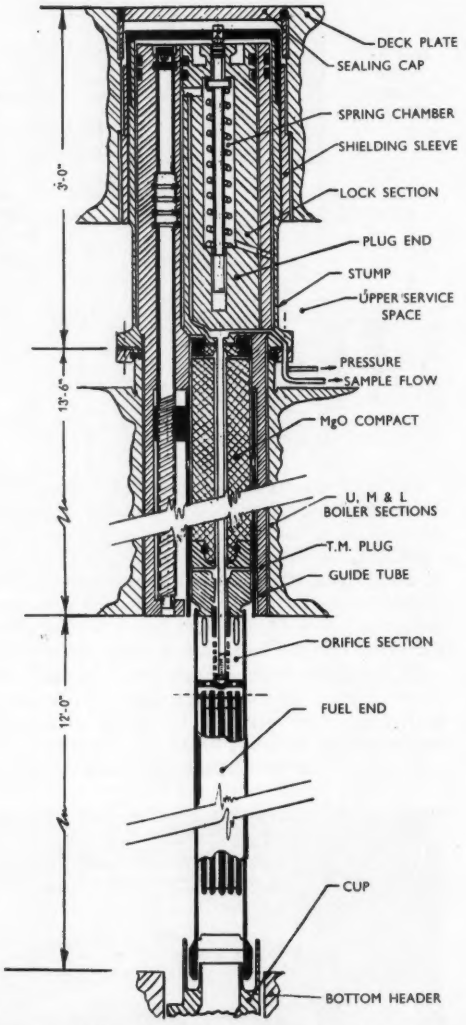
The fuel elements themselves can be considered in two sections, the fuel end and the plug end. The fuel end, which is approximately 12 ft long overall, has its lower end shaped to fit over the spigot in the cup of the bottom header; the upper end is provided with an orifice section having two orifices in series, the first to obtain a graded

† Laurence states 199 fuel elements.



(Left) Aluminium cladding for fuel.

(Right) Section of a fuel unit showing tube lowering mechanism.



flow to suit the element's position in the lattice and the second to provide a small pressure drop (about 5 p.s.i.) to provide a flow for cooling the plug end, and to feed a sampling line so that each element can be monitored for flow, activity and temperature. The orifice sizing is not carried out on an individual basis, but elements are divided into six flow groups ranging from 170 gal/min to about 40 gal/min.

Each of the cups in the lower header is designed to have a definite leak into the main mass of heavy water surrounding the fuel rods, so that some 10%‡ of the total flow passes through the general mass and 90% through the element tubes themselves.

The diameter of the element tube, which is of aluminium, is 2¼ in.; the fuel is in the form of five flat plates sheathed in aluminium. There is a total of approximately 120 lb of uranium per fuel element.

The plug end of the fuel element is approximately 15 ft 6 in. long, of which the lock section, at the top, accounts for about 2 ft 6 in., the remainder, the spacer section, consisting of a thick-walled aluminium tube with solid plugs at each end and two concentric thin-walled tubes up the centre for monitoring take-offs; the remainder of the space being filled with magnesium oxide.

T.M. Plugs

An important feature in the design of NRU is the arrangement made for continuity in cooling of the fuel element, even during fuel changing. Mention has already been made of the permanent tubes, extending from the top header into the service space, through which the fuel element passes. In effect, during fuel changing, these tubes are telescopically extended right down the length of the fuel element and into the cup on the bottom header thus completely enclosing the fuel element. This is achieved by the use of a thin-walled aluminium guide tube which is extended downwards into the reactor when required by a rather complex mechanism known as the tube mechanism plug, or T.M. plug.

Something over 16 ft long, these plugs provide a housing for the guide tube, and raise and lower it by means of a screw mechanism, operated from the fuel-changing flask. The T.M. plug is machined throughout from stainless steel, the upper thrust guide bearing and thrust bearing being of micarta and the lower of aluminium-7% tin alloy. Each unit weighs 400 lb and is said to have cost $8,000.

As will be seen from the sectional drawing, the T.M. plug provides a housing for the fuel element proper which, due to the space taken up by the lead screw is 15/32 in. offset from the centre of the permanent tube. In order to compensate for this, the cup in the bottom header is also offset by the same amount.

‡ Laurence gives 5% of the total flow, not 10%.

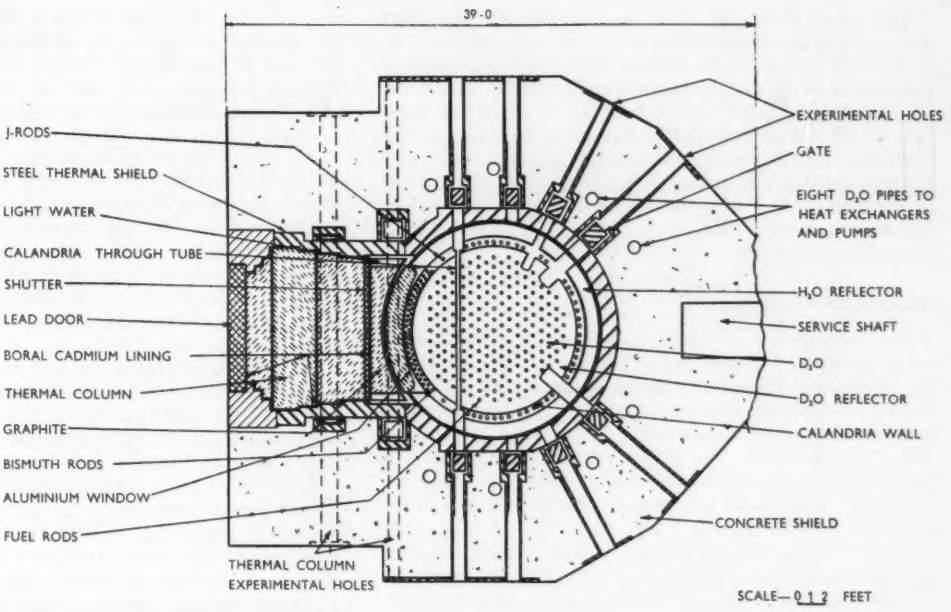
Control and Safety Rods

There are 16 control and safety rods, 13 of cadmium and 3 of cobalt, supported by stainless-steel tubes 10 ft long by 3½ in. dia. Raising and lowering is by motor-driven screws, with magnetic release for gravity-operated spring-assisted emergency operation.

The rods are divided into three groups or banks, the first two each comprising four rods and reducing the reactivity by about 0.036. Bank 3, with eight rods, reduces the reactivity by about 0.074. For a "conditional" trip, i.e., one due to coolant failure or appearance of abnormal amounts of radioactive material in the system only one bank of rods will fall. For an "absolute" trip all rods are released.

J-rods

The annular space in which the irradiation of isotopes takes place has, as its two walls, the outer wall of the calandria and the inner wall of the light-water reflector. This, incidentally, has a thick outer wall but a very thin inner wall which is braced to the outer wall by five stiffening rings. The bottom is extended to the bottom



Sectional plan of reactor. Note slight displacement of core lattice where the horizontal facility passes through.

flange of the calandria. The side walls are interrupted for a space of 8 ft square for the thermal column, and a thin aluminium "window" replaces it to contain the gas filling of the J-rod annulus, and to prevent the escape of heavy water which would fill the annulus if the calandria should fail.

The annulus has positions for 42 "small" J-rods and four "large" J-rods. Each hole is equipped with an aluminium tube or thimble passing right through from the master plate to the lower service space, the lower end being provided with bellows seals. The J-rods themselves have a plug end about 15 ft long and a fuel end, containing the thorium or isotope for irradiation about 13 ft long. Cooling throughout is by light water.

The diameter of the tubes for the small J-rods is 2 in. in the calandria region and 4¼ in. for the large J-rods. In actual fact, no design exists for "rods" in the true sense for these larger units, although one hole is to be used for a pneumatic tray rod.

Table 1—Engineering Design Data

Inside height of reactor shell (distance between header blocks)	12 ft
Inside diameter of reactor shell	11 ft 6 in.
Width of J-rod annulus	6 in.
Inside diameter of water reflector	12 ft 6 in.
Outside diameter of water reflector	14 ft 8½ in.
Thickness of steel shield	12 in.
Outside diameter of steel shield	17 ft 1½ in.
Approximate thickness of concrete shield	9 ft 6 in.
Approximate diameter of shield	26 ft
Number of lattice positions	218
Number of positions occupied by control-shut off rods	16
Number of special loop positions	3
Number of positions available for fuel and research	199
Lattice spacing	7¾ in.
Length of uranium	10 ft
Weight of uranium per assembly	120 lb
Maximum coolant velocity	33 ft/sec
Maximum heat transfer at 200 MW	630,000 B.t.u./ft²-h
Maximum surface temperature	215°F (102°C)
Maximum uranium temperature	370°F (188°C)
Heavy water temperature in	120°F
Heavy water temperature out	167°F
Heavy water circulation	22,000 gal/min
Heavy water in reactor vessel	86,000 lb
Heavy water in system	130,000 lb
Natural water through main heat exchangers	20,000 gal/min
Pumping power for heavy water	1800 h.p.
Length of tubing in main heat exchangers	70 miles

Table 2—Estimated Neutron Balance

$\eta = 1.326$
$\varepsilon = 1.017$
$p = 0.912$
$f = 0.955$
k_∞ at 20°C $= 1.175$
$L^2 = 0.0147$ m²
$L_s^2 = 0.0127$ m²
$B = 3.28$ m^{-2}*

Escape Loss	−0.085
Temperature Correction	−0.009
Samarium Capture	−0.006
Xenon Capture	−0.029
	1.046
Available Surplus	0.046

*B is the geometrical buckling including effects of vacant positions for control-shut off rods, the split in the lattice and re-entrant cans for experimental beam holes.

B-rods

The 57 bismuth rods are located in the J-rod annulus covering the opening to the thermal column. They are not rods in the same sense as the fuel elements or the J-rods as it is not intended that they should be removed. A ¼-in. dia. cooling tube passes right through the centre of the tube and the bismuth, which is in the form of a 2-in. (approx.) annulus cast around the cooling tube for a length of approximately 9 ft to give 6 in. overlap at the top and bottom of the thermal column opening.

View on top of reactor, showing stumps and caps.

The use of the B-rod screen has considerably simplified many of the design problems of the thermal column. By its filtering action on the gamma radiation it has reduced the heating in the thermal column sufficiently to enable the air-cooling channel to be set back 10 in. from the inner face of the column, instead of having to be almost at the inner face. Had this been the case it would have necessitated a complicated closed circuit air-cooling system on account of the high level of argon-41 evolved. As it is, the level of this isotope in the effluent air is low enough to permit of a once-through system.

Heavy-water System

The main circuit of the heavy-water system is from the outlet at the top header of the reactor to the inlet at the top of the heat exchanger, thence to the circulating pump and into the bottom header of the reactor. There are eight heat exchangers and eight pumps each capable of handling some 2,800 gal/min. The pumps are of stainless steel and have double mechanical shaft seals. Half the pumps are driven by single-speed a.c. motors and half by two-speed a.c. motors with auxiliary d.c. motors. All are fitted with flywheels and there are two separate power supplies, one from Des Joachims and one from Bryson, automatic change-over being arranged in the case of failure of one system.

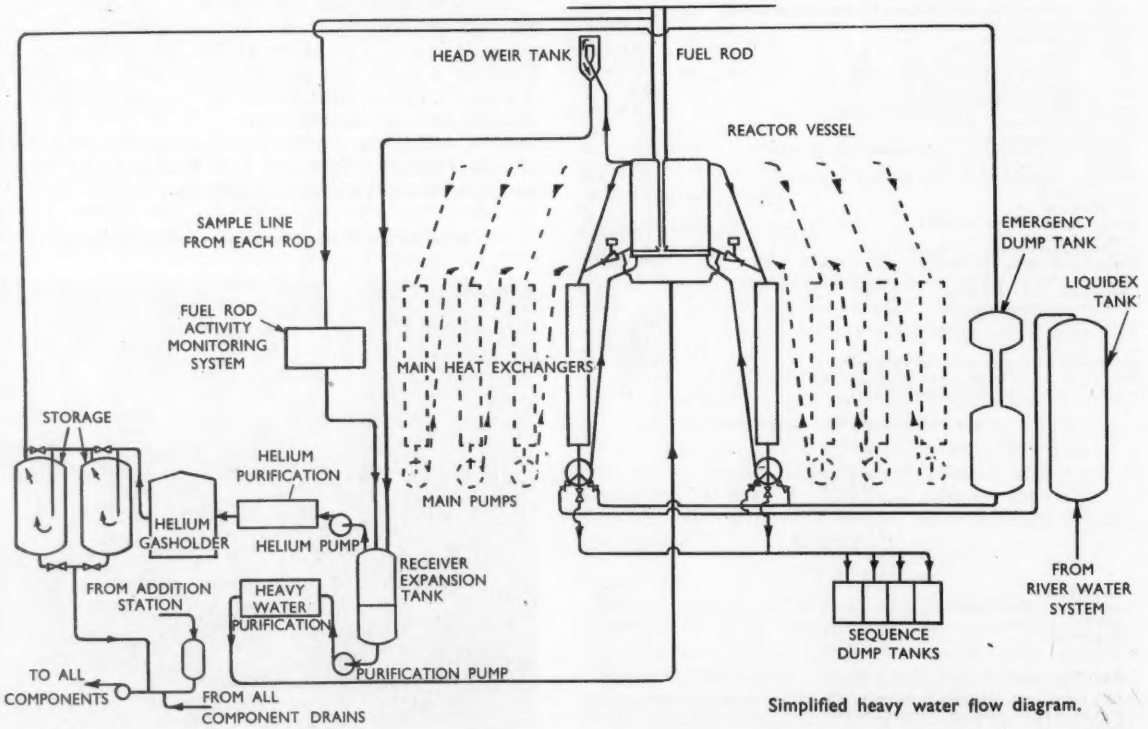
The heat exchangers are of the shell and tube type, in stainless steel throughout, and have double-tube sheets and metal bellows expansion joints. The use of tubes only $\frac{3}{8}$ in. o.d. in order to obtain the best practicable area-to-volume ratio, introduced some pretty problems in tube expanding, there being 2,869 tubes 16 ft long in each unit. However, freon-tightness was achieved in all the heat exchangers, with a large proportion even helium-tight—something of a triumph for the Andale Company who built the heat exchangers.

The inlets of 4 and 5 heat exchangers are provided with by-pass lines connected to the bottom of the calandria, so that in the event of a loss of heavy water causing a lack of head to the pumps a supply sufficient for shut-down cooling purposes could still be achieved. The by-pass valves open automatically on the occurrence of a drop in pressure at the heat exchanger inlet.

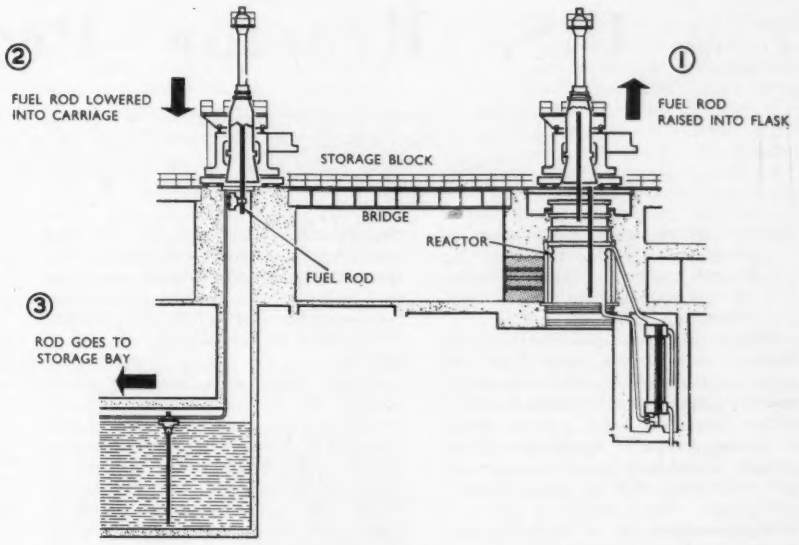
Normally the pressure on the heavy-water system is maintained constant by allowing a controlled flow over a weir enclosed in a helium-filled tank near the top of the reactor. Down in the basement there is a receiver-expansion tank—usually known as the expansion tank, which is connected to the weir tank by a large pipe that normally does not run full and thus induces a flow of helium along with it so that the helium " blanket " over both the tanks is continually mixed.

The expansion tank is the reservoir from which both the helium and the heavy-water purification systems draw their supplies. Some 250 gal/min of heavy water is drawn from the expansion tank and discharged through nozzles into a degassing tank where dissolved and entrained gas is removed by ejector and returned to the expansion tank for subsequent removal to the helium purification system. From the degassing tank the heavy water is first cooled from about 167°F to 100°F in a heat exchanger, passed through a number of filters and, finally, through ion-exchange columns before being pumped back into the bottom header of the calandria.

The helium, at the rate of about 4 cu. ft/min is drawn from the expansion tank through a condenser drier where some of the entrained D_2O is condensed out, and then through a catalytic recombination unit after which it flows through freezer-driers before entering activated carbon absorbers. Part of the helium then returns to the main gasholder which has a capacity of 2,000 cu. ft. The remainder, about 2.2 cu. ft/min is pumped into a small high-pressure gasholder from which it flows through the G.F.P. (gaseous fission product) monitor system and back to the expansion tank.



Simplified heavy water flow diagram.



Schematic diagram of fuel changing.

Dump System

Dumping, in NRU, does not appear to be a method of reducing reactivity in emergency (as, for example, the dumping of the reflector in DIDO) but seems to be considered solely in terms of a possible calandria failure. There is a series of " sequence " dump tanks in a basement which are connected to the drain from the J-rod annulus.

The emergency dump tank is, in reality, two tanks situated one above the other and connected by a vertical pipe. The lower tank will take a proportion of the D_2O rapidly, and the rate will then be reduced. The final level is some 6 in. below the level of the D_2O in the reactor, so that there will be enough to provide cooling for the fuel rods.

It was originally decided to use a liquid that was not miscible with either light or heavy water and had a specific gravity different from either, to prevent heavy down-grading of heavy water by light water in an emergency, and a " Liquidex " tank was provided. The idea of a special liquid has now been abandoned, but the name is still applied to the tank which actually contains distilled water. If any D_2O has been lost prior to dumping, it will be necessary to admit light water into the system since the fuel elements must be cooled at any cost. Since, however, the sequence dump tanks into which escaping D_2O is drained fill in sequence by automatic valves, the first tank will contain practically uncontaminated D_2O since the system is arranged so that light water is only added as D_2O is drained away.

Secondary Cooling

From an installation on the bank of Ottawa river, a pumphouse supplies some 25,000 gal/min of river water from a depth of 80 ft. Approximately 20,000 gal/min is utilized for the main reactor cooling, the remainder being fed to the auxiliary circuits.

The auxiliary circuits comprise (1) the grouped J-rod circuit, comprising 40 J-rod positions; (2) the individual J-rod positions, comprising six circuits; (3) the B-rod circuits; (4) the reflector; (5) the thermal shields; (6) the experimental hole gates; (7) the experimental hole plugs; (8) the interspace concrete.

Auxiliary cooling throughout is indirect, the primary coolant being distilled water in a closed circuit with a helium atmosphere, and ion-exchange purification, with heat exchangers cooled by river water. Certain of the circuits are arranged so that river water may be used directly in emergency.

Rod Handling

The two large mobile flasks on their travelling gantries are shown in the cross-sections of the reactor building. The X-rod flask, for fuel elements, is normally located at the East wall of the building and the J-rod flask on the West wall. Both have built-in cooling, utilizing heavy water for the X-rod unit and distilled water for the J-rod unit. A new fuel rod, carefully dried in a special drying unit so that the heavy water is not contaminated with atmospheric moisture, is lifted into the cylinder of the flask and indexed round. The flask then moves up to the rod position in the reactor and the nose sealed to the stump by a bellows assembly. The guide tube inside the reactor is then lowered, the flask circulating system started up, and the extractor engaged. The rod is then lifted just clear of the core and left for about 15 min for some of the activity to decay, and then raised into the flask after which the cylinder is indexed round again and the new rod lowered into place. After the operation is completed, the irradiated rod is lowered down the elevator at the storage block end of the building down to the storage pond.

Experimental Facilities

NRU has 27 horizontal facilities through the shielding, some being 12 in. and some 6 in. diameter. Many are extended into the core region and there are two through tubes of elliptical cross-section 3¼ in. by 4½ in. in a region where the flux is nearly 3×10^{14} n/cm²-sec. Beam holes are provided with cooled gates just outside the thermal shield, the gates contain potassium metaborate. Shielded flasks are provided for 12-in. and 6-in. plugs up to 14 ft 5 in. long and give a shielding equivalent of 10 in. lead for the inner 6 ft tapering down to 2 in. at the outer end of the plug.

The thermal column is 8 ft square at the inner end, 10 ft square at the outer end and 12 ft long. A boral-cadmium-lead shutter is provided about 30 in. from the inner end to enable safe access to the outer end of the column to be obtained when the reactor is shut down. The outer door of the column is of lead, 14 in. thick, and lined with boral and cadmium. At the outer end of the column the flux is of the order of 10^{10} n/cm²-sec.

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U.S. Reactor Progress

The following digests of papers delivered at the recent Atomic Industrial Forum give a brief summary of the general state of a number of U.S. schemes, some of which have not yet been described in detail.

Nuclear Development Corporation of America—Chugach Association Inc. Project. Leon Malin (Nuclear Development Corpn. of America). Paper No. 57-AIF-42.

This project sometimes known as the SDR, is for a 10 MW power plant with a reactor cooled by sodium and moderated by heavy water. Since the feasibility of the design rests entirely on the ability to develop a suitable barrier between the sodium and heavy water an extensive test programme will be necessary as a preliminary. Static testing on tubes and headers is scheduled to begin at once; barrier development will, it is expected, commence within a few weeks. A full coolant mock-up is scheduled to start work in March, 1958.

City of Piqua, Ohio Project. Dr. Chauncey Starr (Atomics International). Paper No. 57-AIF-43.

This project is for a 12.5 MW power plant with an organic moderated reactor and its progress will largely depend on the results obtained with the OMRE (*Nuclear Engineering*, December, 1957, p. 521). The current schedule provides for commencement in October, 1958, and completion in May, 1961.

Progress Report on the Dresden Station. Vaughan D. Nixon (General Electric). Paper No. 57-AIF-44.

The Dresden power plant has an output of 180 MW and operates on the dual cycle boiling water principle developed by G.E., and will be owned by the Commonwealth Edison Co. Bechtel Corporation are undertaking construction services and design of conventional portions of the plant. Basic information is being provided by the G.E.'s 5-MW pilot plant at Vallecitos which recently went on load.

Detail design is about two-thirds complete and construction is well under way, the containment sphere being partly erected, and due for completion in April, 1958. The major equipment from subcontractors is also proceeding as planned. Completion is scheduled for early 1960 and it is expected that regular operation will commence later in the year.

Consolidated Edison Indian Point Nuclear Power Plant. Gordon Milne (Consolidated Edison Co. of New York). Paper No. 57-AIF-45.

There have been several changes in detail design of this scheme which is to provide 275 MWE (gross) by means of a pressurized water reactor with 112 MW oil-fired superheater. The zirconium clad thorium fuel plates originally planned have been abandoned in favour of a mixture of uranium and thorium oxides clad in stainless steel. It has also been decided not to provide for entrance into the containment sphere during operation, thus reducing the amount of shielding required inside the sphere and enabling its diameter to be reduced from 190 to 160 ft.

Major design items still not settled include the relative amounts of excess reactivity to be controlled by the control rods and by boron poisons in the primary coolant and the fuel; the method of removing fuel elements from the reactor to the fuel handling building; details of waste concentration and disposal plant. Major conventional equipment has been purchased, and The Babcock and Wilcox Co. are proceeding with initial fabrication of the reactor vessel and steam generators. The containment sphere has not yet been ordered pending settlement of the fuel handling arrangements. On site an access road has been built and rock excavated for the conventional plant and condenser intake. The probable completion date is still given as late 1960 but rising costs of sub-contracts and changes in design indicate that the final cost may be about $90 million.

This station was first described in *Nuclear Engineering* for September, 1956, p. 241.

Consumers Public Power District of Nebraska Project. Dr. Chauncey Starr (Atomics International). No. 57-AIF-46.

This project, better known as the SGR or sodium graphite reactor, is an extension of the design of the Sodium Reactor Experiment which was dedicated on November 14. Brief descriptions of both the SRE and the SGR appeared in *Nuclear Engineering* for February, 1957, page 78, but some of the information given for the SGR has since been modified. Steam conditions are now 800 p.s.i. and 825° F (previously 850 and 833 respectively), the sodium inlet and outlet temperatures being 500° F and 925 ° F. The original fuel element design was based on the use of metallic uranium; it now appears possible that uranium oxide may be used. A considerable amount of development work is required on the steam generator and superheater, and a quarter-scale prototype is to be tested with the SRE.

Homogeneous Reactor Experiment No. 2. S. E. Beall (Oak Ridge National Laboratory). No. 57-AIF-48.

HRE2, sometimes known as HRT, had its operation delayed by stress-corrosion cracking, caused by chloride-ion contamination, late in 1956. This necessitated the replacement of 132 flanges and 10,000 ft of tubing in the leak detector system. Prior to this replacement a series of engineering tests which had been interrupted were continued while replacement material was obtained. During January-March, 1957, the reactor was operated for 1,382 hours, including 665 hr. with water at full temperature and pressure, 520 hr. at 1,700 p.s.i. and 280° C with depleted uranium in the form of uranyl sulphate solution.

Repair work was completed in August, 1957, and during September-October 750 hours operation at full design conditions have been achieved. Critical experiments are expected to begin in January.

Nuclear Merchant Ship Propulsion Plant Status Report. C. W. Hasek Jr. (The Babcock and Wilcox Company). No. 57-AIF-50.

Designed for an output of 20,000-22,000 s.h.p., this plant is of the pressurized water type with two steam generators and high- and low-pressure turbines operating on the same shaft. The projected core will consist of 32 fuel elements each containing 200 stainless steel tubes with 3% enriched uranium oxide.

The primary cooling system operates at 1,750 p.s.i. and mean water temperature in the reactor of 508°F so that steam will be delivered at varying pressures from 715 p.s.i. at no load to 470 p.s.i. at 22,000 SHP. Criticality of the reactor is expected in January, 1960.

Pennsylvania Power and Light Company Project. W. E. Johnson (Westinghouse Electric Corporation). No. 57-AIF-51.

The Pennsylvania Advanced Reactor (PAR) is a homogeneous design with uranium thorium slurries. The reactor is not scheduled for completion till 1962 and the present position is that after a considerable amount of preliminary work on loops of laboratory size—200 gal/min—the programme will shortly be extended to cover further study on a 4,000 gal/min loop, which will be one half of the capacity of one loop of the proposed plant.

Enrico Fermi Atomic Power Plant Status Report. John Anderson (Power Reactor Development Co.). No. 57-AIF-53.

This fast breeder reactor design was described in *Nuclear Engineering* for March, 1957. Criticality, at one time anticipated in December, 1959, is now expected to be postponed till the autumn of 1960, with commercial operation in the autumn of 1961.

Yankee Atomic Electric Co. Project. A. E. Voysey (Westinghouse Electric Corporation) and Roger J. Coe (Yankee Atomic Electric Co.). No. 57-AIF-55.

This is a pressurized water reactor plant of 134 MW to be located near Rowe, Massachusetts. The fuel will consist of some 20 tons of slightly enriched uranium in the form of sintered pellets of uranium dioxide.

Work on access roads and railroads will begin shortly and major construction in the spring. Completion is scheduled for 1960.

Vallecitos Developmental Boiling Water Reactor. Samuel Untemeyer II (General Electric Company). No. 57-AIF-111.

This reactor has already been referred to in Paper 57-AIF-44 on the Dresden station, for which the Vallecitos is acting as a pilot plant. It has, incidentally, the distinction of being the first plant to operate that has been completely financed by private capital, being a joint effort of General Electric and Pacific Gas and Electric Company.

The Argonne Boiling Reactor (ARBOR) Facility Status Report. L. W. Fromm (Argonne National Laboratory). No. 57-AIF-41.

This reactor is intended to extend the work done on boiling water reactors with BORAX at atmospheric pressure and 300 p.s.i., and with EBWR at 600 p.s.i. ARBOR is intended for a maximum power level of 400 MW, and pressures of 600-2,000 p.s.i., with forced circulation flows up to 36,000 gal/min. It is to be located at NRT (Idaho) and detailed design is scheduled to permit construction to start in the summer of 1958, initial operation being scheduled for mid-1960.

Westinghouse Electric Corporation-Duquesne Light Company Project. Robert Kettner (Westinghouse Electric Corporation).

Better known as Shippingport, this reactor will be the U.S. first full-scale power plant and, as is generally known, is a pressurized water design. The first core, consisting of 32 seed assemblies containing highly enriched uranium and 113 blanket elements with natural uranium dioxide, was installed on October 6. The testing programme became intensified during the summer, and hydraulic tests of 3,750 p.s.i. were held for 30 min on August 22. The Duquesne Light Company is completing training for operating personnel. Reactor diverged Dec. 2, 1957.

Sodium Reactor Experiment. Frank Faris (Atomics International). No. 57-AIF-24.

The SRE, briefly described in *Nuclear Engineering* for February, 1957, went critical on April 25, the first generation of electrical power being on July 12, 1957. Full-power operation is not envisaged, however, until early in 1958; it is considered essential, in a basic high-temperature experiment such as this is, to adopt a conservative policy.

Valuable maintenance experience has been obtained with the removal of a damaged fuel element, and the removal of a disposable cartridge from one of the cold traps. A pump is to be added between the plenum feeding the spaces between the moderator cans and the main primary sodium system, as there have been signs that the can cooling is greater than was anticipated. The plant is said to have performed well—if anything, beyond expectations, and the reactor stability has been gratifying.

Army Package Power Reactor. Kenneth Kasschau (Alco Products, Inc). No. 57-AIF-20.

The APPR was originally described in *Nuclear Engineering* for July, 1956, and a further article in August, 1957, reviewed some of the problems arising and their solution. Some 3-4 million kWh of operating experience has been gained and, so far as can be determined in the early stages of operation, has exceeded design specifications in all respects, although total core life cannot yet be assessed, of course. An interesting feature is that a major portion of all the troubles that have occurred has been with the conventional plant and components.

Experimental Breeder Reactor No. 2. L. J. Koch (Argonne National Laboratory). No. 57-AIF-47.

EBR2 is a fast breeder design for sodium cooling, with a thermal output of 62.5 MW and a net electrical output of 20 MW. Its most significant feature is the use of recycled fuel after pyro-metallurgical processing, which is involving a great deal of work on casting techniques to produce the pin-type elements required.

Major construction at the site is scheduled to begin in the spring of 1958 and be complete by the end of 1959.

Liquid Metal Fuel Reactor Experiment (LMFRE) Status Report. Robert T. Schomer (The Babcock and Wilcox Company). No. 57-AIF-49.

This project is for a reactor operating with a circulating fuel of uranium dissolved in bismuth, and a breeding fluid of a slurry of thorium-bismuthide dissolved in bismuth. It is still in the " reference design " stage and no date has yet been assigned for construction.

Experimental Boiling Water Reactor. J. W. Harrer (Argonne National Laboratory). No. 57-AIF-21.

The EBWR has now had 10 months' operation, logging some 2,000 MWd, the equivalent of 100 days at full power. Actually, it has been in operation at less than full power for some 50% of the time, since its purpose is to produce information rather than demonstrate the simple ability to operate continuously.

It has, incidentally, shown considerable flexibility in operation and has, in fact, frequently been started up just to show to visitors. Maintenance appears to be relatively easy; activity in the condenser, for example, is less than 1 mr/h after one day's shutdown.

Further experience with water treatment seems to be necessary if aluminium condenser tubes are to prove successful; there were considerable deposits of heavy metals inside the tubes, and lighter deposits outside. Metallic deposits are also found on the fuel elements.

The EBWR, described in *Nuclear Engineering* for March, 1957, p. 121, has shown disappointing results from the cost point of view, an analysis showing a cost of 52 mills/kWh. It is considered that capital costs, the largest single item, could be reduced by increasing the size of the plant. The next largest item is fuel fabrication, which could, it is pointed out, be reduced in the case of multiple units.

Status Report on the Engineering Test Reactor. Richard L. Doan (Phillips Petroleum Company). No. 57-AIF—2.

The ETR was described in *Nuclear Engineering* as recently as November, 1957, following its official opening on October 2. While all new reactors usually fall short of original expectations when first operated, the ETR seems to have more than its fair share of troubles, most of which seem to be concerned with the fuel elements. The change from the MTR design with its curved plates to flat plates 50% longer and with thinner outer plates has produced an element which is mechanically weak in comparison. While the MTR plate deflects 0.010 in. for a 21 p.s.i. pressure differential, the ETR plates give the same deflection with only 2.5 p.s.i. Pre-reactor hydraulic flow tests gave not merely excessive distortion but actual collapse of the plates at less than the design flow rate (30 ft/sec in the element against 35 ft/sec). There is also a variation of as much as 25% between different channels, while the overall water flow required to give the design velocity in the element is something like 55,000 gal/min in place of the 49,000 estimated or the 44,000 originally announced. Suggestions for improving the position include perforation of the side plates to relieve the pressure differential between channels; roll-swage cold fabrication techniques that leave the plates in a hardened condition; a re-design to provide a central support for the plates along the lines of SPERT. At the moment, upper limit flow of 18 ft/sec has been imposed, which will limit the maximum power to 90 MW.

At the same time, there are considerable discrepancies in the actual nuclear results compared with the original design estimates. The excess reactivity for the core loaded with 49 fuel elements and aluminium filler pieces in the experimental facilities has been found to be 1.5% instead of the predicted 11%; apparently due to excess of boron.

The average value of the black shim rods has been discovered to be 1.5% in

place of the predicted 3.6% $\delta k/k$ which, as the report states, "will introduce some problems in operation."

Trouble has also been experienced with control and shim rods from the mechanical standpoint. Owing to a design error, the pressure drop through the fuel section of the control rods is found to be some 50% higher than that calculated to give the necessary coolant velocity. Corrosion troubles with carbon steel actuator rods were found to prevent scramming after a week's intermittent operation, and has necessitated replacement by stainless steel. The drive rod magnets have been modified since holding force was inadequate.

Characteristics of the scram arrangements for power failure have been found to be unsatisfactory. The frequency relays give a scram time of 0.225 sec, but the undervoltage relays take 2.25 sec, and the flow recorder (back-up protection for these two) takes 12 sec. It will be necessary to add at least two fast-response pressure differential scrams before the reactor is taken to full power.

At present the maximum power to which the ETR has been operated is 2.5 kW.

Advanced Reactor Session

A Plasma Fission Reactor. R. L. Aamodt (Los Alamos Scientific Laboratory). Paper No. 57-AIF-103.

The plasma fission reactor has been approached as an exercise in the extrapolation of existing techniques far beyond the point of present-day engineering knowledge. The calculations that have been made indicate that the concept is marginal, but a new kind of power plant may become a reality after sufficient research effort is expended. The system aims at converting the heat energy from fission into electrical energy without passing through a steam phase. The reactor comprises essentially a gaseous fissile mass, surrounded by a liquid moderator such as heavy water. Bell and Safonov, in a study of the criticality of such a device, came to the rather surprising conclusion that a mass of fissionable material of less than one kilogramme would become critical in a 1-ft radius sphere (if the surrounding moderator were heavy water), with a particle density less than atmospheric, or 2.7×10^{19} molecules/cm^3. For larger radii the critical mass goes up, but the density drops to perhaps 10^{17} particle/cm^3, or 1/270th of atmospheric pressure at room temperature and 1/27th of atmospheric pressure at 3,000°K.

In the cavity reactor, the gas is transparent to fission neutrons, but up to 75% of the moderated neutrons are reflected back into the cavity to maintain the fission chain reaction. It has been suggested by Colgate that the energy generated in such a cavity could be used to generate a shock wave in a tube. The heated gas behind the shock front then passes through a magnetic field and forces the magnetic field aside. The gas is slowed down in the process and some of its kinetic energy is transferred to magnetic field energy which can be converted to electrical power in an external circuit. The gas passes on and piles up at the other end of the tube, where it is again heated by the fission process and a new shock wave forms to repeat the cycle. Because the gas spends only a short time in the magnetic field before being re-formed by the walls of the cavity, and because a shock wave is an especially stable phenomenon, hydrodynamic instabilities will not have time to grow. This, then, is the particular concept which was examined in more detail. In a conceptual model the cavity is envisaged as a cylindrical chamber 25 ft in diameter and 150 ft long. Surrounding this is a thin carbon liner, a metal tank and the heavy water moderator (Fig. 1).

The amount of fissionable gas is adjusted so that, when it is uniformly distributed, the system is just below criticality. Any perturbation that increases the amount of fissionable material in one end will result in neutron multiplication and heating of the gas in that end. If the heating takes place rapidly enough, the consequent expansion of the gas will cause a shock wave to form in the tube. The gas behind the shock front is heated by passage through the shock front and follows the shock front at a slower velocity. The temperature of the column of gas behind the shock front is sufficiently high to ionize the gas. The column then becomes a conductor and passage of this conductor through a magnetic field at the centre of the reactor compresses the lines of force, which can penetrate the conducting gas slowly, into the region near the coils. The force between the gas and the magnetic field slows the column of ionized gas to approximately one-half its original velocity, giving up to three quarters of its kinetic energy to the magnetic field. If this energy is extracted from the magnetic field before the column passes out of the field region, a net amount of energy has passed into the magnetic field and on out into the external circuit in the form of electrical energy.

The gas moves on to the other end of the cylinder, cooling as it goes, and piles up in the far end to repeat the cycle.

Assumptions made in the design parameters were that the gas was uranium metal (boiling point 3,900°K) surrounded by a cylindrical graphite container. The maximum heat flux through the graphite is 1 kW/cm^2 and the inside wall temperature 3,500°K. This in turn is surrounded by the heavy water blanket. The mechanical to electrical conversion desired is around 70%, including thermodynamic efficiency. From these assumptions it was calculated that the gas will radiate as an opaque body with the required heat flux when the maximum internal temperature is 6,500°K. To keep the necessary conversion efficiency, the radius of the reactor must be 4 metres. This figure is determined by the velocity of the plasma which at 6,500°K is 1.6×10^5 cm/sec. A reasonable gas density would be 5×10^{17} at/cm^3, which, if uniformly distributed at 6,500°K, would correspond to a pressure of less than 1 at. Pressure in the region of the shock wave would then be about 1.5 at. In order that the cylinder should be large enough for a shock wave to form before the gas enters the magnetic field, the length must exceed 6 diameters and would preferably be of the order of 150 ft. A crude estimate of the power output yields a figure of 500 MW. Approximately one half of the energy of expansion would go into kinetic energy. Of this about 75% would be converted into electrical energy resulting in 37.5% efficiency. In the ideal case, radiation losses may be expected to cut this to approximately 20% for overall efficiency.

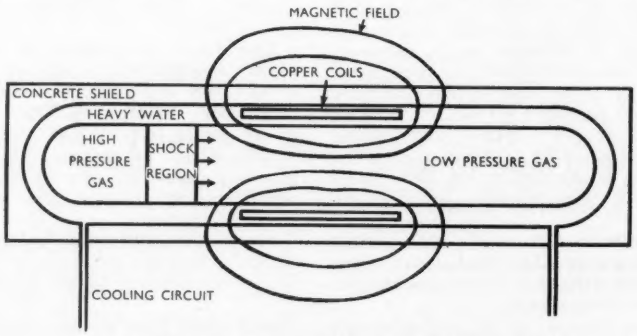


Fig. 1.—Schematic diagram of the plasma fission reactor.

The system has been studied, not only as a possible alternative approach to power generation but to show that the fission field has still great potentialities and it is suggested that of the many ideas that have been proposed, some successful method for the direct production of electrical power from a fission reactor will be forthcoming within a few years.

Nuclear Thickness Control

Baldwin "Atomat" on Precision Rolling Mill

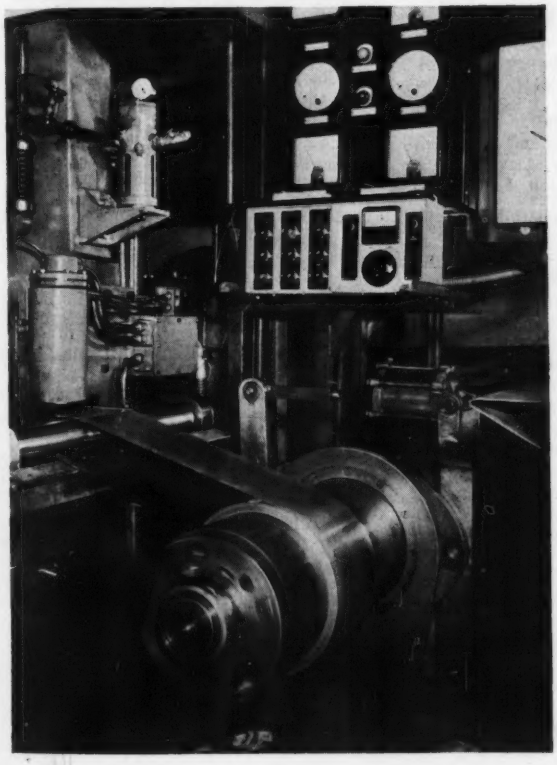
WHAT is believed to be the first British application of a nuclear gauge to thickness control, as distinct from measurement, is now in operation at the Birmingham works of D. F. Tayler and Co., Ltd., where a Baldwin "Atomat" gauge has been fitted to a brass strip cold finishing mill.

The mill, manufactured by W. H. A. Robertson and Co., Ltd., of Bedford, is capable of finish-rolling of brass strip up to 15 in. wide, and down to 0.004 in. thick, at rolling speeds up to 500 ft/min, in coils up to 5 cwt. Of the 4-high type, it has work rolls of 5¼ in. dia, and back-up rolls of 15 in. dia, the face width of all rolls being 18 in. The roll screwdown is accomplished by two 4-h.p. motors connected by a magnetic clutch, thus allowing simultaneous or independent adjustment as required. The main mill motor is of English Electric manufacture, rated at 100 h.p. and there is a 15-h.p. coiler motor. The mill has been in operation since 1955 and its inherent ability to produce strip to close tolerances has now been more fully exploited by the addition of automatic control of roll setting by an "Atomat" equipment manufactured by the Baldwin Instrument Co., Ltd.

The Baldwin "Atomat"

The principles of the Baldwin thickness gauge have already been reviewed in these pages (*Nuclear Engineering*, September, 1956, p. 244) and an account of a gauge operating on a steel rolling mill was given in the May, 1957, issue, p. 219. The absorption of radiation passing through a strip of metal will, of course, vary with the thickness of the metal. In this particular application, deviation from a normal pre-set reading is utilized for operating the roll screw-down motors. The measuring head is located between the rolls and the reeler and consists of a transmitter which emits bremsstrahlung radiation from a metal target bombarded by beta radiation from a strontium-90 source, and a receiver. The latter consists of a scintillation counter using a sodium iodide crystal and a photo-multiplier cell. The output from this is proportional to the radiation received and, hence, to the thickness of the strip, and is balanced against the output from a network which represents the desired thickness, as controlled by a "set thickness" potentiometer. Any unbalance represents a deviation from standard thickness and is fed into a high-gain d.c. amplifier, to operate an indicator, a recorder, and a discriminator unit which determines the action to be taken according to the "tolerance zone" into which the deviation falls. The normal working tolerance on this particular mill is 0.0003 in. and if the deviation falls within the "dead" zone, i.e., within plus or minus this figure, the discriminator takes no action. If the deviation exceeds this, the screw-down motors are operated for ¼ sec at 2 sec intervals, until the deviation returns to the dead zone. Should the deviation exceed 0.0005 in., the screw-down motors are operated continuously until the thickness returns to the inner control zone.

The control system is automatically cut out at low strip speeds, i.e., when running up at the beginning of a strip, to guard against hunting at low strip speeds, or damage to the rolls should the mill stop with an over-size strip in the gap.



(Top of page) General view of the Robertson mill.

(Left) View of coiler end showing Atomat gauge and indicator panel.

Standardization

The measuring head is self-standardizing when withdrawn from the operating position by an air cylinder. The source unit is fitted with a shutter having three apertures, one with lead (for "infinite" thickness), one with a piece of 0.030 steel for middle ranges and one left open (zero thickness) for the lowest ranges. The appropriate aperture is automatically moved into position according to the range-setting switch. If any drift has taken place in the calibration a balancing potentiometer is operated to restore conditions to normal.

Technical Papers and Publications

IRON AND STEEL INSTITUTE

High Boron Alloy Steels for Reactor Control Rods. By T. J. Middleham, J. R. Rait, D.Sc., F.I.M., and E. W. Colbeck, M.A., F.I.M. (Hadfields Ltd.).

This paper, published in the Journal of the Institute (September, 1957) and presented at the Autumn General Meeting, outlined work carried out in response to the need for boron containing steels for control rods in nuclear reactors. The very high thermal neutron capture cross section of the boron is of great value to nuclear engineers engaged in the design of reactor control mechanisms. The class of steels on which the experiments had been carried out were difficult to work, and their extreme brittleness rendered them unsuitable for structural or engineering use. The research had led to the discovery of a new technique for the production of boron iron alloys containing up to 4.75% boron, which can be successfully forged, rolled and extruded, and alloys containing up to about 6% boron which can be successfully cast. Mr. Middleham described methods of manufacture, with particular reference to the influence of aluminium on the hot workability, results showing an increase in forgeability with Al content up to a maximum of about 2%. The physical and mechanical properties of the boron steels were described and reference was made to their application in thermal nuclear reactors.

During the subsequent discussion, Mr. G. T. Harries referred to work carried out along similar lines by Jessops, but in this case the boron-containing alloys were based on stainless steel.

Dr. McIntosh (Culcheth Laboratories, U.K.A.E.A.) traced the history of the development of control rods in this country for which he had been responsible. In BEPO boron was introduced as a compound enclosed in a tube but for the Windscale reactors it was necessary to develop alternative methods based on an alloy of high neutron absorbing power. A possible alloy was a steel containing 2% boron with the necessary strength at temperature and adequate oxidation resistance. Approaches to five of the leading steel makers in the country led to work being carried out at Hadfields, Jessops, and Brown-Firth laboratories. Dr. McIntosh instanced this co-operation as yet another example of the excellent way in which the steel industry was willing to undertake development work in the early days of atomic energy in this country. He then drew attention to the need for programmes aimed at the development of shielding alloys, suggesting this as a rewarding field for future investigations in view of the great need, particularly with nuclear power propulsion, to reduce the mass of material required for shielding.

L. M. Wyatt (U.K.A.E.A. Risley) referred to the design of the control rods. It was necessary to evolve a design which exposed a large area of rod of sufficient thickness and absorption to be black to neutrons. A quarter of an inch of 4% boron would meet this requirement. The duty of these rods was light, normally only the tip entering the neutron flux. In the case of Calder Hall it was estimated that even with exposure throughout the full life of the reactor, only 10% of the boron would be lost. Thus the blackness of the tip of the control rod would not be seriously reduced. In the forthcoming round of industrial reactors with a higher flux and a higher burn-up it would be necessary to include a higher proportion of B^{10} isotope in the steel or alternatively to replace the control rods during their life. The B^{10} isotope separation was practicable. The embrittlement produced by helium formation from B^{10} would limit the concentration of B^{10} that was feasible. Mr. Wyatt suggested boron carbide steel cermets as an alternative, on the argument that here the embrittlement due to helium production would be confined to the boron carbide.

INSTITUTION OF MECHANICAL ENGINEERS

Effects of Nuclear Radiation on Hydrocarbon Oils, Greases and Some Synthetic Fluids, V. W. David and R. Irving (Shell Research, Ltd.).

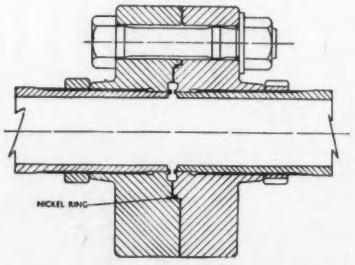
The effects of nuclear radiation, in particular pile radiation, on a range of hydrocarbon mineral oils, greases, and some synthetic fluids have been investigated. Under such conditions, hydrocarbon oils cross-link and increases in viscosity occur to varying extents according to the composition of the oil; solidification ultimately takes place with unstable materials over the range of irradiation dosages covered in this work. Using viscosity measurements as a criterion of radiation damage, aromatic compounds naturally present in refined mineral oils were found to have a beneficial effect whilst oils of high viscosity (and molecular weight) were less stable than were materials of lower viscosity. Although various aromatic additives, naphthalene, phenanthrene, and phenyl alpha-naphthylamine, conferred some protection to hydrocarbon oils against radiation damage at the concentrations used (1 to 2 per cent by weight), the effect was small compared with that achieved by variations in oil constitution. Irradiation experiments using high-energy electrons and gamma rays have been correlated with those from pile investigations, and there are strong indications that similar processes are occurring under the three conditions; this correlation has been extended to include the cross-linking of an oil by chemical (*t*-butyl peroxide) treatment.

An examination of the behaviour of various metallic soap-hydro carbon oil greases showed that such systems can rapidly become fluid at relatively low irradiation doses, indicating a significant breakdown in the soap structure.

A short description is given of the behaviour of various synthetic fluids (including silicone oils) to pile irradiation. It is concluded that, as a class, hydrocarbon mineral oils are relatively radiation-resistant materials and warrant close examination as potential lubricants for moving parts exposed to high-energy radiation.

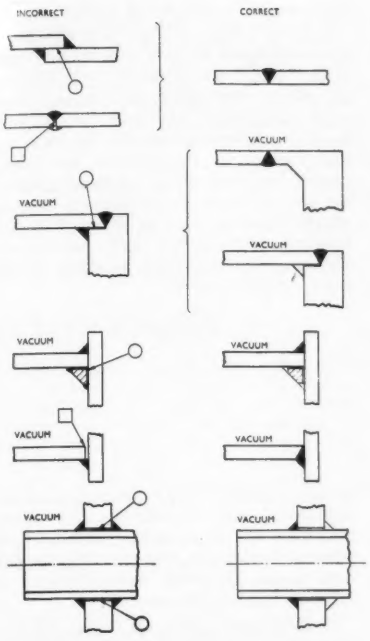
Vacuum Techniques in the Atomic Energy Industry, H. Knonberger (U.K.A.E.A. I.G.).

Vacuum techniques are used in two distinct fields: (1) applications where a vacuum is required as an essential part of the process, and (2) applications in which vacuum techniques are merely used to ensure the tightness of plant (which may not finally be required to operate under high-vacuum conditions). Advances in vacuum technology have made the construction and testing of plant to vacuum standards a relatively simple matter.



Flange joint of 2,500 p.s.i. water at 350°C (2½ in. pipe).

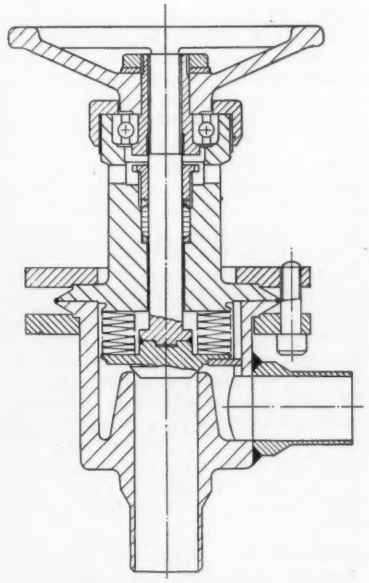
Examples are given showing how vacuum techniques are used in the uranium 235 diffusion plant, in plant handling liquid metals at high temperature, in experimental work for pressurized water reactors, and in the testing of the Calder Hall heat exchangers.



Examples of good and bad welding practice. Shaded fillets represent intermittent welds, white circles indicate trapped volume and white squares dirt traps.

The success of vacuum techniques in large-scale applications depends on three factors: correct design of plant, the availability of simple and reliable testing methods, and on efficient managerial control of construction and test work.

Basic design rules are given and illustrated by examples of flanges, valves, and other components used in the applications mentioned above. Vacuum testing methods are discussed. The charcoal-Pirani technique of testing is favoured for most applications; tests can be carried out on components before they are degassed and "clean"; equipment and operation are simple. The management of vacuum work is discussed and a method of quality control by means of binomial distribution charts is described which has been useful in improving systematically the vacuum tightness of manufactured components.



An example of vacuum techniques applied to the design of a valve for liquid sodium.

INSTITUTE OF MARINE ENGINEERS
(Joint Nuclear Marine Propulsion Panel).

The Nuclear Propulsion of Ships, Sir Christopher Hinton, K.B.E., M.A., F.R.S. and R. V. Moore, G.C., B.Sc. (Eng.), M.I.Mech.E., M.I.E.E.

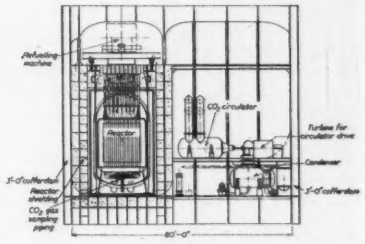
The general conclusion to be drawn from this paper is that it is not possible to foresee a reactor system likely to be economical in smaller ships. While the pressurized water reactor can certainly be made light enough for submarine propulsion it is questionable whether it can be economical due to the necessity for highly enriched fuel. The gas-cooled reactor seems a possibility for ships of 25,000 s.h.p. or above.

The design of effective extended surfaces for fuel elements is involved, and has required a considerable amount of experimental work. It seemed that the solid rod was reaching its limit of development, and increased ratings would have to be achieved by increasing the surface/volume ratio which would, of course, involve slight enrichment. Nevertheless, if, for example, the use of flat plates or rod clusters increased the surface/volume ratio by a factor of 30, the specific rating for equivalent conditions would be increased by a factor of five, so that a very substantial reduction in weight per h.p. could be achieved.

Increased reactor rating implied an increase in neutron flux density and, of course, increased irradiation and corrosion damage. It was essential that limits were firmly established and, where necessary, materials developed to withstand the conditions.

The margin between the operating temperature and the melting point of canning material would be very much increased if zirconium were substituted for magnesium, the respective melting points being 1,850°C and 630°C. The poorer thermal conductivity of the zirconium and its poorer nuclear properties would require about a 50°C increase in the maximum fuel element temperature and a slight increase in enrichment. In power station work indications were that best results could be obtained with uranium oxide elements clad in beryllium which has a melting point of 1,280°C and low neutron absorption. This would enable the rating of the reactor to be raised still further and the size of the heat exchangers and turbine equipment to be reduced.

Design investigations have been carried out for a 50,000-s.h.p. unit and Table 1 shows the approximate particulars of the design.



Section of 50,000-s.h.p. marine reactor unit.

The reactor pressure vessel is supported directly from the tank bottom of the ship within the biological shield which is lined internally with a thick mild-steel plate in which 80-90% of the radiation is attenuated. The centre of mass of the graphite moderator is situated some 8 ft below the centre of the roll of the ship. Two parallel cooling circuits are provided, each with its own heat exchanger and gas circulator, which are connected to each other and to the pressure vessel by two 2 ft 6 in. diameter ducts with creased bends.

Table 1. Proposed nuclear-propelled ship

Deadweight	101,000 tons
Displacement	140,600 tons
Block coefficient	0.77
Length overall	975 ft
Beam	145 ft
Speed	18.25 kt.
Reactor heat output	180 MW
Pressure vessel dia.	18 ft
CO_2 pressure	315 p.s.i.
Enrichment	1.3 × normal
Steam conditions (single cycle)	500 p.s.i. 730°F

The heat exchangers are supported, with their axes horizontal, to the side and forward of the reactor at tank top level. The two turbo-driven circulators lie between the inner longitudinal bulkheads in a separate flat some 15 ft above tank top level. The reactor is loaded and unloaded with uranium from the top, the deck for this operation being 20 ft below upper deck level, the intervening space housing the necessary machinery.

The reactor control room is positioned immediately aft of the reactor above the engine-room, in close proximity to the control equipment. The control rods are mounted on either side of the reactor vessel in compartments shielded from the gas ducts.

The weight per s.h.p. achieved for the reactor unit and all machinery was about 500 lb per s.h.p., of which nearly half is due to radiation shielding required round the reactor unit itself. It is interesting to see that this value represents a very big reduction from the Calder Hall plant and, if present trends are maintained, is a value that will not be reached on land-based plants before the mid-1980s.

If a figure of 180 lb per s.h.p. is assumed for the boiler and propulsion

machinery complete for an equivalent conventional plant with turbo-electric drive, it is seen that the nuclear plant is about three times as heavy, of which a large proportion is due to the shielding.

This is not the complete story, however, because the conventional plant requires 5,000 or 6,000 tons of bunker fuel oil at the outset of a voyage, whereas the nuclear plant requires only 15 tons of uranium, which is sufficient to fuel the ship for about a year. If the weight of bunker fuel is added to the weight of the conventional plant, then the weight per s.h.p. rises from 180 lb. per s.h.p. to 425 lb. per s.h.p. roughly equivalent to the alternative nuclear plant.

As the design of this particular nuclear plant materialized, it was found that this rough weight equivalence was also repeated on a volume basis, the length of machinery space to accommodate the reactor unit and main machinery being about 24% of the length of the ship compared with some 17-18% in the case of a conventional tanker.

" One is forced to the conclusion," the paper concluded, " that at present it is not possible to foresee a reactor system which is likely to be economical in smaller ships. This, of course, does not mean that such reactors will not be discovered. Development is taking place at a surprising rate and all of this development tends in the direction of lower weight per horse power, and lower capital and fuel costs. Although today we are not able to foresee the reactor which could be used in ships of 20,000 tons capacity and less, such reactors will almost certainly become available within ten to twenty years."

New Books

Theories of Nuclear Moments. By R. J. Blin-Stoyle. (90 pp., Oxford University Press, 8s. 6d. net.)

One of the problems at present facing teachers of physics at university level is how to fit the teaching of an ever-expanding subject into a course of fixed duration. Short of increasing the length of courses in proportion to the amount and complexity of the subject, one answer would be to limit undergraduate teaching to what is at present called classical physics and omit all modern work and ideas. Such a system would have obvious drawbacks, and so it is not surprising that all universities try to effect a compromise between the old and the new, resulting in an ever-increasing gulf between the newly-qualified graduate and the physicist well-versed in research. Those needing to span the gap generally do so by rapidly tracing the broad outlines of development in their field, then filling in the details more slowly. This process can be helped by volumes of this type, since the subject-matter is at post-graduate level, and is presented as a survey with ample references where further details are required.

The book is the first of a new series of monographs (Oxford Library of the Physical Sciences) aiming to cover the whole of physics and allied subjects at post-graduate level. One of the declared aims of the series is to produce books at a modest price by limiting the length of each monograph to between 30,000 and 40,000 words and by printing a large edition. This aim accounts for the binding in thin boards but otherwise the volume is up to the high standard maintained by this publishing house in other series of text-books. The scope of the present volume is presumably an indication of the form of the remainder of the series.

The present ideas about nuclear moments are given here in an easily digestible form for research workers in nuclear physics. This is done with a minimum of mathematical detail while each chapter has a summary of foregoing arguments. The result is a survey of nuclear moments from their definition, through experimental measurements to the predictions of various nuclear models and their shortcomings.

The prime virtue of this volume is that it condenses much valuable information and presents it in summary form. A defect on the other hand is one that might be expected from a work of this kind; through striving after brevity, some sections suffer from a rather cursory treatment. However, this is offset by the large number of references quoted, which most readers would need to consult to amplify the material presented here.

The book gives an excellent summary of the experimental methods used for measuring the spins and magnetic and electric moments of nuclei and goes on to indicate the attempts that have been made to link these measured properties with a model of the nucleus. The current particle models and the collective model are discussed with indication of their successes and failings. The models are then analysed in terms of their predictions about moments of nuclear ground states. There is a brief discussion on higher multipole moments than magnetic dipole or electric quadrupole and also on the moments of excited states. The latter is a field where experimental data are rare and its importance could be more emphasized. Since developments in nuclear physics are so rapid, this up-to-date survey will unfortunately age within a few years but not, it is to be hoped, before it has introduced many new research workers to the problems in this particular aspect of nuclear physics.

J.M.C.

Radiation Shielding. By B. T. Price, C. C. Horton, and K. T. Spinney. (300+pp. Pergamon Press, London, 1957. 60s. net.)

In this book of over 300 pages, the authors state their aim as that of providing a text-book rather than a ready-reckoner, with a view to giving the reader a " feel " of the subject. What class of reader the authors have in mind is not made clear, but it is certainly no newcomer to nuclear engineering or even nuclear physics. The book is, in fact, an excellent work of reference for those already well versed in the subject with which it deals, and is copiously provided with tables, diagrams and references to other sources of information.

A brief opening chapter discusses the permissible levels of different types of radiation from the aspect of biological safety. This is followed by some 80 pages on the attenuation of gamma rays, and their generation by fission product decay and the arrest of electrons. The third chapter is devoted to the physics of the neutron as a discrete particle, and deals with the various ways in which it may interact with atomic nuclei.

Up to this point, the book pursues well-defined paths. It is in the further chapter, however, that it comes up against the less well charted topic of neutron attenuation in thick shields. This subject is treated comprehensively and some useful ideas not hitherto published appear to have been introduced. It is, nevertheless, difficult to infer from the treatment presented precisely how numerical computations on this aspect of shield design should be made. The chapter is concluded with a helpful discussion on ducts and voids in shields.

In the fifth chapter, formulæ are derived which relate radiation intensity to various standard arrangements of source and shield. A final 100-page chapter deals with the application of the theory so far discussed to practical shielding problems. An account of heat generation by capture gamma rays in shields is followed by consideration of the resulting temperature distribution. Possible materials for thermal and bulk shields are noted and their mechanical and nuclear properties surveyed, together with estimates of their relative cost. Radiation arising from neutron activation is discussed, particular reference being made to reactor coolant circuits.

This book can be strongly recommended to those who feel the need of an up-to-date work of reference on shielding, provided, however, that they are well acquainted with the subject.

After a number of delays Shippingport nuclear power plant went critical on December 2, the anniversary of Enrico Fermi's discovery of the sustained chain reaction. The station is scheduled for full operation within a few weeks. The pressurized-water reactor, built by Westinghouse, is designed for an output of 60 MW; a new core, giving a greater output is being developed.

World News

International

Sir Edwin Plowden, chairman U.K.A.E.A., returned to the United States during November for further talks with Mr. Lewis Strauss, chairman U.S.A.E.C., on the sharing of nuclear information. On December 10 it was announced that Sir Edwin would be a member of the Government's team for the North Atlantic Treaty Organization talks in Paris. One of the chief objectives of the N.A.T.O. talks is to draw up plans for greater scientific and political co-operation within the Atlantic alliance.

United Nations General Assembly has unanimously approved the agreement governing the relations between United Nations and the International Atomic Energy Agency. At the same time a further resolution was passed authorizing the I.A.E.A. to consult the International Court on legal matters.

Report published by the joint committee of the European High Authority and the Council of Ministers shows that unless nuclear energy is developed as a source of power the energy imports of the European Coal and Steel Community will have to be tripled by 1975.

Following ratification of the European Common Market and Euratom treaties by the Netherlands both treaties will come into force on January 1.

U.N.O. Food and Agricultural Organization is to step up research into the agricultural use of nuclear energy, a plenary conference of the organization decided on November 19. A resolution seeking preliminary steps towards an agreement with the newly formed International Atomic Energy Agency was also adopted.

United Kingdom

The Nuclear Power Plant Co., Ltd., have received from Ing. Mattei, president of ENI (Ente Nazionale Idrocarbi), Rome, a letter of intent to negotiate the construction of nuclear power stations in Italy, and also to conclude a long-term agreement for mutual co-operation on the design and development of power reactors. The agreement will be made between the N.P.P.C. and AGIP Nucleare, a subsidiary of ENI, and will refer to gas-cooled graphite-moderated reactors.

The first station to be constructed under this arrangement will have an output of 200 MW and will involve the manufacture in the United Kingdom of considerable quantities of plant. The Nuclear Power Plant Co. will be responsible for the overall design and satisfactory commissioning of the station, while AGIP Nucleare will place local contracts and carry out the site erection. The technical agreement, which involves a full exchange of information, was concluded with the assistance of U.K.A.E.A., who were requested to give ENI general guidance last July. The signing of the agreement was closely followed by a visit to Rome of Mr. D. E. H. Pierson, secretary, A.E.A., with a view to drafting an agreement covering the supply of British nuclear reactors to Italy.

The Canadian trade mission, which has just concluded a month's visit to the U.K., has had plenty of opportunity of seeing, at first hand, the excellent progress being made in the application of nuclear energy by British concerns. Members of the mission—which comprised over 50 business men interested in purchasing heavy machines and equipment—were taken to A.E.R.E., Harwell and Berkeley nuclear power station. The team also visited many factories including those of the following companies:—Accles and Pollock, John Thompson, Babcock and Wilcox, C. and J. Weir, Motherwell Bridge and Engineering, Metropolitan-Vickers Electrical, B.I.C.C., English Electric, Rolls-Royce, English Steel and B.T.H.

First British pumped storage scheme is now operating at Glen Shira in Argyll. The turbo-generator develops 5MW.

New safety precautions have been announced in Scotland to handle the potential risks from emergency conditions arising in nuclear plants at Dounreay, Hunterston and Chapelcross. The moves for creation of local safety organizations have been promoted by the A.E.A. In Caithness, a liaison committee has been formed to link A.E.A. and county authorities in making suitable safety precautions against an incident of the Windscale type at Dounreay. Similar plans are being prepared for operation at Chapelcross while Hunterston will come into the picture at a later date.

Plans for the training of atomic energy students at Dounreay have taken positive form with the entry of the first group of block release students from the U.K.A.E.A. Dounreay project at Robert Gordon's Technical College, Aberdeen. These students will finish their present course at the end of December and will be followed by subsequent groups from Dounreay.

Central Electricity Authority and Electricité de France have agreed to proceed with the scheme for linking the French and U.K. electricity systems by a cross-Channel power cable. It is hoped to complete the project by the winter of 1960-61. The total cost will be £4 million and the annual savings to both countries about £300,000.

The six-mile approach road to the Hinkley Point nuclear power station site has now been completed by Taylor-Woodrow Construction Ltd. The contract was placed by Somerset County Council a few months ago.

Gel Tankers, Ltd., of London, has reached agreement with Maierform S.A. Geneva, the naval architects, for joint preliminary investigations into the commercial construction of nuclear-powered submarine tankers of 68,000 tons deadweight.

Reactor School at Harwell is to increase the number of courses held each year. Four standard courses of 16 weeks' duration will be held instead of three. The fee remains at £250. In addition there will be two nine-days' courses for senior technical executives costing £50.

Argentine

A.E.C. has signed an agreement with the Province of La Rioja designed to stimulate exploration for uranium metal. Price will be 300 pesos per kilo for yields of 4% and 400 pesos for larger yields.

Brazil

Dr. Juscello Kubitschek, president of Brazil, announced on November 26 that his country was seeking a bilateral agreement with the U.K. for atomic reactors, fuel and technical personnel. The statement followed a ten-day visit to the U.K. by Admiral Cuhna, head of the Brazilian Atomic Energy Commission. It has been suggested that Brazil could offer thorium in return because of the country's large reserves of monazite.

Canada

Sectional meeting of the World Power Conference takes place in Montreal from September 7 to 11, 1958. Theme will be " Economic Trends in the Production, Transportation and Utilization of Fuel and Energy." Authors of the 16 papers to be presented by the British National Committee include Sir Christopher Hinton and Mr. L. Rotherham, together with Messrs. J. A. Jukes, R. T. Moore, H. West, J. Henderson and C. L. C. Allan.

Denmark

Spokesman for the Danish A.E.C. said on December 4 that a serious defect had been found in a reactor tank shipped from the United States. When the tank was subjected to a water test, it appeared to leak in several places. The tank was to have been used in an American research reactor at the nuclear energy centre at Risø.

Helsingør Shipyard has been awarded a contract to build a lead-lined steel tank for Risø's PLUTO.

Fiji

Radioactive deposits have been discovered in Fiji, Sir Ronald Garvey, the governor, told the opening budget session of the Legislative council on November 22. He said the discovery had been made by geologists of the Lands, Mines and Survey department when it investigated copper deposits at Nukudamu, near Udu Point.

France

Professor Frances Perrin, led a delegation of the Atomic Energy Commission of France on a visit to Moscow on November 15.

Germany

West German A.E.C. has approved an eight-year nuclear power reactor programme with a capacity of 500 MW. The cost, about £200 million sterling will be raised jointly by the state and industry. A security commission will supervise the reactor programme.

Atomics International is planning closer co-operation with W. German companies. At a press conference on December 4, a spokesman said A.I. sought collaboration " because of the combination of high-class German workmanship and American know-how."

Canada and West Germany signed a ten-year agreement for co-operation in peaceful uses of atomic energy on December 10. The agreement will be used as a pattern for bilateral pacts with other countries. West Germany will buy 500 tons of uranium under the agreement, to be shipped over a five-year period.

India

Dr. Bhabha, chairman, A.E.C., said on December 9 that a study of the economics of power generation in India revealed that in most parts of the country nuclear power would be more economic than coal. A heavy water plant was being set up at Nangal: the cost of the product would be very low, even lower than in the United States.

Israel

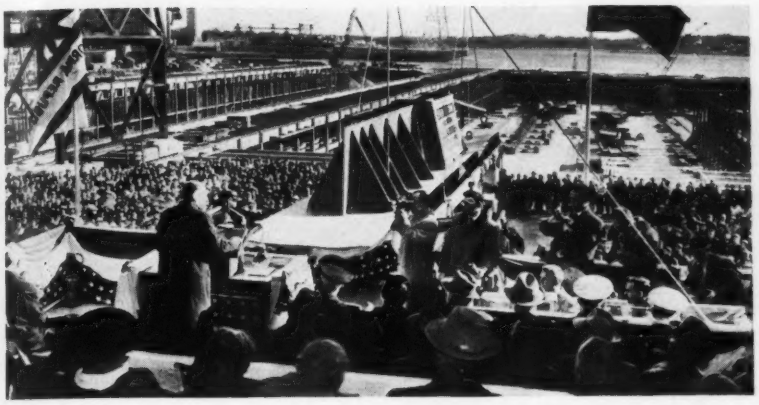
Second season of courses in the use of radioactive isotopes, run by the Weizmann Institute, commenced in December, 1957. The use of radioactive isotopes is rapidly growing in Israel; many agricultural, industrial and medical institutions seek the advice of the Weizmann Institute in the solution of the various problems that arise from commercial applications. Such courses at the Weizmann Institute, lasting two to three months, have so far been completed by about 70 engineers, chemists and agriculturists. During this winter electronic engineers will also be trained in the assembling and repair of radioactive isotope testing apparatus.

Mr. Teng Chao-Ming, secretary-general of the Chinese Technical and Economic Miss on and Mr. Liao study a construction-phasing model in the operations room at Berkeley. With the po.nter is Mr. Hooper of A.E.I.-John Thompson.

Representatives of the Japanese A.E.C., led by the deputy chairman, Mr. Ichiro Ishikawa, visited Berkeley nuclear power station on November 13. He was impressed by the progress already made by A.E.I.-John Thompson.

(Left) Fifteen members of the Canadian Trade Miss on led by Mr. Duncan and accompanied by Sir William McBride of the Dollar Exports Council were shown round Berkeley by Sir Edward Thompson on November 26.

Uranium elements fabricated by General Electric were handed over to representat ves of the Spanish Government at Idlewild airport recently. (Right to left) John Davis Lodge, U.S. Ambassador to Spain; Wesley M. Johnson of the U.S. Atomic Energy Commission; Don Jose Vergara Doncel, technical representative of the Nuclear Energy Commission of Spain; Count of Motrico, Spanish Ambassabor to the United States, and W. R. Herod, President of the International General Electric Co.



Keel-laying ceremony of the first U.S. Navy nuclear-powered surface vessel, the guided missile carrier U.S.S. "Long Beach," on December 2. The Lt. Governor of Massachusetts, Robert F. Murphy, addressed guests. The 8-ton keel is 60 ft long.

Italy

Twenty companies have expressed an interest in the projected 150 MW nuclear power plant for SENN (Societa Elettronucleare Nazionale) in the South of Italy. The companies included two French, one Canadian, one Belgian, five British and eleven American. SENN had asked the companies to confirm by December 15 their intention to submit a firm proposal within six months.

On December 7 Professor Dr. Ing. Guilo Battistini, president of a committee for the safety and economics of nuclear plants, Italian National Association for the Control of Combustion, led a delegation to the U.K. Purpose of the visit was to study problems of safeguarding workers in the projected Italian nuclear power stations.

Japan

U.S.A.E.C. office has been opened in Tokyo to assist in the scientific and technical aspects of atomic energy development. Mr. W. H. Pennington, an accredited attache to the U.S. Embassy in Tokyo, has been appointed scientific representative to head the office. He will be assisted by Mr. P. A. Roessler.

Atomic Energy Commission of Japan is planning an Asian Atomic Energy Forum in Tokyo during 1958, with the object of forming an Asian counterpart of Euratom. A spokesman for the commission said on November 24, that invitations would be sent to 16 Asian nations through the Japanese Foreign Ministry.

Sweden

A. B. Atomenergi has requested the Government for an allocation of Kr.138 million in the next budget (fiscal year beginning July 1, 1958). This year the atomic energy budget was Kr.63.5 million.

U.S.A.

New York Shipbuilding Corp., of Camden New Jersey, have been awarded the contract for the first U.S. nuclear-powered merchant ship, the N.S. "Savannah." The contract, on a fixed price basis for $20,908,774, has been placed by the Maritime Administration, U.S. Dept. of Commerce and the A.E.C. The company will be responsible for the installation and testing of the nuclear propulsion system which is being supplied under separate contract (worth $9.8 million) by Babcock and Wilcox Co. According to the design, prepared by George G. Sharp, Inc., the all-welded N.S. "Savannah" will have the following characteristics: length, 587 ft; beam, 78 ft; full load displacement, 21,800 tons; deadweight, 10,190 tons; normal s.h.p., 20,000; service speed 20 knots.

Thirty containers of uranium elements fabricated by General Electric were handed over to a representative of the Spanish Government at Idlewild airport on December 5. These elements, valued at $112,000 will fuel the 3MW (thermal) open pool reactor which General Electric is supplying for training. The reactor, located at Moncloa, a suburb of Madrid, is scheduled for operation in March, 1958.

One-year contract awarded to R.C.A. Service Co., Inc., by U.S.A.E.C. for construction of a reactor simulator for training armed forces personnel. The simulator is required as part of the U.S. Army's package power reactor programme at Fort Belvoir, Va.

Three-day conference between the A.E.C. and representatives of leading U.S. industrial companies and organizations concerned with the exploitation of nuclear energy, was held behind closed doors in December.

U.S.A.E.C. permits. To University of Florida for construction of a low-power (10kW heat) light-water cooled, graphite moderated and reflected nuclear reactor for training purposes. The reactor will be built by General Nuclear Engineering Corporation, Dunedin, Fla. To AMF for export of a 1 MW pool type light-water training reactor to Societa Richerche Impianti Nucleari in Milan, Italy. Value $489,000. To The Martin Co., Baltimore, for operation of MPR, an experimental heterogeneous water-moderated pressurized system using stainless-steel-clad enriched tubular fuel elements. Max. power: 10 watts.

U.S.S.R.

"Lenin"—the Soviet nuclear powered ice-breaker—was launched on December 5, at Leningrad. "Lenin" has a displacement of 16,000 tons with a total tonnage in the region of 25,000 tons. Overall length is 480 ft and beam 85 ft. The reactor, which is believed to be water cooled, will produce approx. 42,000 s.h.p. Judging by the accompanying photograph of "Lenin" just prior to launching, most of the reactor has already been installed as buoyancy tanks had to be built on to the stern for the launching. The keel of "Lenin" was laid in 1956 and the vessel is scheduled for completion next year.

On December 5, the Soviet ice-breaker "Lenin," the world's first nuclear-powered surface vessel, was launched at Leningrad. The captain of the vessel, which will go into operation in 1958, is Pavel Ponomaryov.

Orbits in Industry

A CASUAL glance at some of the papers published at the recent Atomic Industrial Forum in New York once again emphasizes the difference between British and American viewpoints on the question of publicity for reactor schemes. In Britain, it is very difficult to find out anything about a new scheme. There are, of course, noteworthy exceptions but, in general, the form is "Don't talk" either before or after criticality. Until the reactor is nearly ready to its last brass button, it is very difficult to get any real information. After criticality, in what the Americans call the "debugging" period, it is even more difficult. If one is rash enough to inquire, one is made to feel as though one has turned up at a funeral and asked the family doctor, in a cheerful bellow, what went wrong.

The Americans, on the other hand have, apparently, no inhibitions; either before or after. As soon as the design begins to take shape on the drawing board they are willing—nay, eager—to tell you all about it, with full details, flux distribution diagrams, tonic sol-fa setting and ukulele accompaniment. When criticality is achieved and nothing is quite as it was supposed to be they quite cheerfully produce another set of papers that might almost be entitled "Our Clanger—and How We Dropped It" setting forth honestly and forthrightly exactly what went wrong and what they are doing to put it right. There will be many who disagree with this philosophy, but whatever one feels about the expediency of such an outlook, few could fail to admire the courage and honesty of those who appear in Act II.

Silent Efficiency

There are, of course, exceptions, one of the most notable being Shippingport. Now Shippingport really has got something to shout about—after all, it will be the second full-size generating unit in the world to go into service and the largest pressurized water unit yet built. One feels that if it had happened in this country there would have been quite a song and dance about it.

Yet all the time, there has been very little said since the original Geneva paper, although criticality was achieved on December 2. Occasionally the odd picture or cutting floats in, but for the most part, Westinghouse seem to be saying very little and getting on with the job.

General Electric, for that matter, seem to be taking a similar line with Vallecitos which, although it is only 5-MW capacity, is actually working and, moreover, is the first one to do so that has been completely financed without Government assistance.

The Big House

By the time that this issue appears, the Atomic Energy Authority should be in the early stages of organizing the move to their new premises in Regent Street, scheduled for occupation in March.

Since this journal is not a national newspaper, an Imperious Demand is out of place. So, for that matter, is the Humble Petition. Let us settle for the decent compromise, the Civil Request. When the Authority does do its flitting, could things in the new home be arranged so that the P.R. types are located where we can get at them? By all means, let the rest of the place run riot with security precautions; barbed wire, grim-faced guards with tommy-guns, fierce Alsatians, pass-words—the lot, in fact. Let them even throw in crocodile-infested moats and gamma rays if they feel like it. But could we, *please*, call to get our three-bobsworth of photograph or an extra copy of a duplicated hand-out, without having to fill in a form giving name, Christian name, address, who representing; their address, nationality, time of arrival, person wished to interview, nature of business and whether by appointment or not? This ridiculous document which only needs a thumb-print to duplicate the *kipande* carried by the Kikuyu house-boy, is not only essential to get into the press office at present, it is even more vitally necessary to get out again. Furthermore, it accompanies you—rather like a bill of lading—as you are handed from one unenthusiastic guide to another (for you are never allowed to walk from one office door to another without an escort), and your times of receipt and dispatch are recorded in each office.

The crowning fatuity is, of course, the fact that you are not allowed to travel from the reception office to the eighth floor, in the lift by yourself, although the entrance to the lift is in the main hall and the exit on the eighth floor is via an iron cage which, with its two custodians, makes you think you are in Alcatraz or Sing Sing. What anyone expects you to get up to in between, no one knows. Maybe they suspect visitors of a dark desire to alight at an intermediate station and wake up the Ministry of Supply, or wash their hands when the lift is standing at a station.

Perhaps those in charge of these matters are determined to enact the part of Wall in "A Midsummer Night's Dream," with the P.R. Department and the Press playing Pyramus and Thisbe:

". . . And through Wall's chink,
poor souls, they are content
To whisper, at the which
let no man wonder . . ."

If so, let us come back with another quotation, this time from the "Vicar of Wakefield":

". . . The virtue which requires to be ever guarded is scarcely worth the sentinel."

Department of Rosy Dreams

Another example of the necessity for an Ingenious Device is contained in the following extract from a recent paper.

. . . High thermal efficiencies associated with 1,000° F. steam and with pressures in the supercritical range are within the reach of this concept and await principally the solution of metallurgical problems. . . .

Don't we all?

Xless Machines

The statement by Dr. Andrew Booth, as reported in a recent issue of *Technology*, that a computer has succeeded in evaluating π to 3,000 decimal places over a week-end will be highly gratifying to anyone who requires this order of accuracy. To those of us—and there must be other slap-dash old fuddy-duddies who think of π in terms of "three and a bit," this is just another foreshadowing of "R.U.R." The machines are getting above themselves. Not content with their legitimate work, the solution of mathematical problems, they are branching out into sidelines. They are composing melodies, writing love-letters, and supplying such urgent and essential information as an analysis of the Versailles peace treaty and the determination of the order of composition of Plato's dialogues.

No computer has yet, it is true, read a paper before the Computer Society on methods of improving the relatively inefficient human memory-drum, but one feels that it is only a question of time. There is, of course, one other ray of hope in the gloom. So far as our investigations go, no computer has yet written a love-letter *to another computer*, and suggested that, instead of spending the week-end evaluating π they should elope together and have a dear little cash register. So far, in the computer world, there has never been the slightest sign of X rearing its Ugly Head.

Tangent

Personal

Appointments

Dr. Pickavance.

Dr. K. J. Wootton.

Mr. A. Lindley.

Dr. T. G. Pickavance as director, high-energy laboratory of the National Institute for Research in Nuclear Science at Harwell. At present he is deputy head of the general physics division A.E.R.E.

Dr. K. J. Wootton as deputy manager, G.E.C. atomic energy division, at Erith, Kent. The appointment is a new one arising from the continued expansion of the division's staff and activities under its manager, **Mr. R. N. Millar.**

Mr. Leslie Gamage, M.C., as chairman and **Mr. T. W. Heather,** M.C., as director, Pirelli-General Cable Works, Ltd. **Mr. G. A. Baricalla** and **Mr. W. Lewis Smith** (both directors) have been appointed as the managing committee with the assistance of **Mr. J. R. Harding,** the general manager.

Mr. T. W. Heather, Mr. A. L. G. Lindley and **Mr. R. E. Robinson** as assistant managing directors of The General Electric Co., Ltd. **Mr. D. G. W. Acworth** and **Mr. W. J. Bird** as directors. Mr. Lindley will be responsible for production and sales, home and export, of the engineering group. He has played a leading part in the company's entry into nuclear engineering.

With effect from January 1, 1958, the following are appointed regional directors of the Central Electricity Generating Board: **Mr. P. Briggs,** A.M.I.Mech.E., M.Inst.F. (North Eastern and Yorkshire); **Mr. R. L. Batley,** O.B.E., A.M.I.Mech.E. (Midlands and East Midlands); **Mr. A. R. Cooper,** M.Eng., M.I.E.E., M.Inst. F. (Eastern, London and South Eastern); **Mr. A. C. Thirtle,** A.M.I.C.E., A.M.I.E.E., M.Inst.F. (Southern, South Western and South Wales); **Mr. W. C. Parker,** M.I.E.E., M.Inst.F.(North West, Merseyside and North Wales). **Mr. H. J. Bennett,** A.M.I.E.E., becomes controller of London division and deputy director of the Eastern, London and South Eastern region.

The Generating Board have also appointed three chief project engineers. They will take charge of the three engineering project offices which the Board have decided to establish to undertake construction work of power stations including nuclear and associated sub-stations. **Mr. C. W. A. Priest,** B.Sc.(Eng.), A.M.I.Mech.E., M.I.E.E. *North* (North West, Merseyside and North Wales, North Eastern and Yorkshire areas); **Mr. R. R. Maddock,** B.Eng., A.M.I.Mech.E., A.M.I.E.E., *Midlands* (Midlands, East Midlands, and South Wales areas); **Mr. T. Yule,** M.Eng., M.I.C.E., M.I.Mech.E., A.M.I.E.E., M.Inst.F., *London* (London, Eastern, South Eastern, Southern and South Western areas).

Mr. W. J. Rowland, F.C.C.S., as deputy chief personnel officer, **Mr. E. J. Guinness,** D.S.C., as deputy secretary, and **Mr. H. B. Morton** as deputy solicitor of the Central Electricity Generating Board.

Sir John Crabbe, O.B.E., M.C., T.D., and **Sir Ronald Thomson,** D.L., as part-time members of the South of Scotland Electricity Board until December 31, 1960. **Sir Jackson Millar** in a similar capacity until December 31, 1958.

Mr. F. R. Mason succeeds **Mr. J. F. Perry** as managing director of Metropolitan-Vickers Electrical Export Co., Ltd. He also becomes a director of the parent company and Associated Electrical Industries Overseas, Ltd. **Mr. H. F. Bibby** succeeds Mr. Mason as the export company's general manager.

Mr. A. E. Parritt as contracts engineering manager and **Mr. D. Phelps** as manager of the application engineering department, Foxboro-Yoxall, Ltd.

Mr. S. Mackenzie-Owen, M.B.E., as unit manager of Acheson Colloiden N.V., Scheemda, Netherlands.

Mr. J. W. Plowman (Dewrance and Co., Ltd.) as chairman of the British Valve Manufacturers Association for the year 1957-58. The retiring chairman, **Mr. N. P. Newman** (Newman, Hender and Co., Ltd.) has been elected vice-chairman. Members of the executive committee are: **Mr. D. Bailey** (Sir W. H. Bailey and Co., Ltd.); **Mr. F. T. Bintcliffe** (J. Blakeborough and Sons, Ltd.); and **Mr. F. Burgess** (Whites-Nunan, Ltd.); **Mr. G. F. Chambers** (The Bryan Donkin Co., Ltd.); **Mr. A. E. Dickinson** (Smith Bros. and Co. (Hyson), Ltd.); **Mr. D. S. Gardner** (Glenfield and Kennedy, Ltd.); **Mr. H. L. Hammond** (Crane, Ltd.); **Mr. K. M. Leach** (Audley Engineering Co., Ltd.); and **Mr. A. L. Trump** (Saunders Valve Co., Ltd.).

Mr. Alexander Robertson as director of Glenfield and Kennedy (Holdings), Ltd. He is managing director of the subsidiary, Alley and MacLellan, Ltd.

Lord Gridley, chairman, and **Mr. J. W. C. Milligan,** managing director of Southern Areas Electric Corporation, Ltd., with **Mr. S. R. Elliott,** managing director of P.A.M., Ltd., have joined the Board of Designs and Installations, Ltd. **Mr. J. A. Hinds** and **Mr. C. E. Trodd,** previously owners of Designs and Installations, have joined the Board of P.A.M., Ltd.

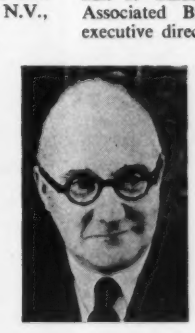
Mr. G. W. Hall, F.R.Ae.S., chairman and managing director of The Fairey Aviation Co., Ltd., has now joined the Board of Atomic Power Constructions, Ltd.

Mr. Maurice Tattersfield as an executive director of the Brush Group, Ltd. He resigns as managing director of the subsidiary, Brush Electrical Engineering Co., Ltd. but remains a non-executive director. **Mr. B. L. Goodlet** succeeds Mr. Tattersfield as managing director and **Mr. R. G. Hooker** becomes director and general manager of Brush Electrical. **Mr. J. Calderwood,** technical director of Associated British Oil Engines, Ltd., as executive director of the Brush Group.

Mr. C. W. Priest.

Mr. R. R. Maddock.

Mr. T. Yule.



Mr. M. Tattersfield.

Mr. B. L. Goodlet

Maj.-Gen. Bols

Mr. A. T. Black

Mr. H. C. Pritchard

Mr. W. H. Apthorpe

Mr. D. Massey

Mr. Arthur Black, C.B.E., as director in charge of the electronics division, The Pena Copper Mines, Ltd., and director of Peto Scott Electrical Instruments, Ltd. The chairman of Pena, **Major-General E. L. Bols,** C.B., D.S.O., has recently announced a diversification of the company's interests through four divisions, metals, electronics, plastics and finance.

Mr. H. C. Pritchard as managing director of Cambridge Instrument Co., Ltd., in succession to **Mr. W. H. Apthorpe**, who is retiring.

Mr. Denton Massey, general manager of A.M.F. Atomics (Canada), Ltd., as vice-president and director in addition to his present appointment. **Mr. Roy B. Snapp** and **Mr. B. V. Eliot** as directors of the company.

Mr. N. C. Lake, formerly managing director of Head Wrightson Machine Co., Ltd., as deputy managing director of Head Wrightson and Co., Ltd.

Mr. Douglas Dodds-Parker, M.P., as a director, and **Mr. Anthony Neville** as manager, Europe, for The Head Wrightson Export Co., Ltd.

Mr. L. C. Percival, chief metallurgist of the British Oxygen Group of Companies, as president of the North London Branch of the Institute of Welding.

Mr. John Dyer has joined the British Electrical and Allied Manufacturers' Association as technical editor of the BEAMA Journal. He was previously public relations officer for E.M.I. Electronics, Ltd.

Mr. D. G. Balfour-Ogilvy as Glasgow area representative of Power Auxiliaries, Ltd.

Following the acquisition of a controlling interest in Bennis Combustion Ltd. by James Hodgkinson (Salford) Ltd., **Mr. G. M. Mellor** has relinquished the appointment of joint managing director of Bennis Combustion Ltd., in order to concentrate on the sales activities of the company. He will continue to serve as chairman. **Mr. B. W. Dawkins** has been appointed joint managing director.

Mr. A. R. Raper succeeds **Major Cuthbert Johnson** as manager, precious metals refinery, The Mond Nickel Co., Ltd.

Retirements

Sir Harry Railing, who recently retired as chairman of The General Electric Co., Ltd., has resigned from the board of Pirelli-General Cable Works, Ltd.

Mr. A. J. Somers, F.R.I.C., retired after 36 years with Borax Consolidated, Ltd.; he was appointed to the board of the parent company in February, 1946.

Mr. W. H. Apthorpe, managing director of Cambridge Instrument Co., Ltd., retires on December 31.

Mr. J. F. Perry, managing director of Metropolitan-Vickers Electrical Export Co., Ltd., and a director of the parent company, has retired.

Major Cuthbert Johnson, manager, precious metals refinery, The Mond Nickel Co., Ltd., retires on December 31, 1957.

Tours

Mr. Dudley Saward, O.B.E., managing director, and **Mr. David Essemont,** C.A., A.C.W.A., controller and joint secretary of Texas Instruments, Ltd., flew to Dallas, Texas, on December 5 for production and marketing discussions with Texas Instruments, Inc., the parent company.

Obituary

Nuclear Engineering records with regret the death of the following personalities:—

Dr. Douglas Whittaker, senior experimental officer, A.W.R.E., Aldermaston died from injuries received in a fire resulting from a metallurgical experiment he was conducting in a laboratory at Aldermaston. It is understood that no radio-active material was involved in the incident. Dr. Whittaker was 39.

Mr. Frank S. Allen, M.I.Prod.E., works director of E. K. Cole, Ltd., and a director of Ediswan-Ekco (Aust.) Pty., Ld., Egen Electric, Ltd., Ekco Electronics, Ltd., and The National Ekco Radio and Engineering Co., Ltd. (India), died on November 20. He was 56 years of age.

Industrial Notes

Ruston and Hornsby, Ltd., of Lincoln, and J. L. Kier and Co., Ltd., of 7 Lygon Place, London, S.W.1, have agreed to collaborate in the design and construction of nuclear power stations ranging from 2 to 25 MW. A joint design team led by Dr. M. Wood will be located at Ruston's Lincoln works.

Col. F. C. Fieldsend will act as liaison engineer between Ruston and Hornsby and the nuclear division of J. L. Kier and Co., Ltd. Mr. H. Kirk, B.Sc., of J. L. Kier, will be resident civil engineer with the Ruston nuclear division at Lincoln.

W. E. Chivers and Sons, Ltd., of Devizes, Wilts, have been awarded a £1 million contract for the construction of the main buildings for the new Rutherford high-energy laboratory on a site adjacent to A.E.R.E., Harwell. The buildings will house the new proton synchrotron which is being built for the National Institute for Research in Nuclear Science. The magnet of the synchrotron will be housed in a concrete building with walls and roof of sufficient strength to support the necessary shielding, the bulk of which will be provided by earth mounds. The roof will comprise 4 ft 6 in. of concrete and 10 ft of earth with provision for adding a further 10 ft of earth over the magnet if this should be found necessary. The main shielding wall separating the magnet room from the experimental area will be of concrete, 28 ft. thick, and with movable blocks up to a height of 12 ft.

The experimental area is to be shielded on all sides by earth banks. External beams are to be absorbed at the ends of long tunnels driven into the back wall of the experimental area and the contours of the site have been exploited to ensure that the most intense particle beams are driven into a hillside and come to rest underground. Shielding overhead will be provided at the targets where necessary.

A control-room block will contain the facilities essential to the remote operation of the machine, together with counting rooms, an experimental preparation area of 4,000 sq. ft and accommodation for the operating crew. The motor alternator house and a laboratory and office block will be located nearby.

William Jessop and Sons, Ltd., Brightside Works, Sheffield, announce that zirconium, reactor grade zirconium, commercial grade zirconium and zirconium alloys are now available from the company's recently installed batch of vacuum melting furnaces.

W. H. Allen Sons and Co., Ltd., Bedford, have received a contract for the construction of steam turbine-driven generating sets in connection with the nuclear submarine, *H.M.S. Dreadnought*, to be built by Vickers-Armstrongs, Ltd. Units will be installed at Dounreay for shore tests and others in the ship. The turbo-generators incorporate electrical equipment supplied by the British Thomson-Houston Co., Ltd. The condensers, which are separate from the turbo-generators, will also be supplied by W. H. Allen.

Birlec, Ltd., Tyburn Road, Erdington, Birmingham 24, have recently received further orders for dryers in connection with nuclear power stations. The latest of these orders are from Sunvic Controls, Ltd., for two standard Birlec absorption dryers to provide dry air to the control instruments at Berkeley, and from the Nuclear Power Plant Company, Ltd., for a unit to dry compressed air for testing reactor vessels at Bradwell.

The Scientific Instrument Manufacturers' Association of Great Britain (SIMA) has booked 5,000 sq. ft of stand space at the second Atoms for Peace Exhibition in Geneva (September 1-14). Twenty-five member companies of the Association have already indicated their intention to exhibit.

Matthew Hall and Co., Ltd., Dorset Square, London, N.W.1, welcomed over 500 guests at their annual cocktail party and exhibition in London early in December. Models and photographs showed the company's increasing participation in nuclear engineering.

Measuring Instruments (Pullin), Ltd., opened a private exhibition of contemporary instrumentation at Electrin House, 93-97 New Cavendish Street, London, W.1, on December 2. The exhibition marks the 21st anniversary of the company's foundation.

Ketay, Ltd., of Romford, Essex, in conjunction with **Norden-Ketay Corporation** in the United States, has recently concluded a licensing agreement with **Societe Anonyme Precilec** of France. This agreement provides for the manufacture under licence, and sale, of Ketay and Norden-Ketay servo-mechanisms in France, together with an interchange of technical and manufacturing information between the three companies.

The Solartron Electronic Group, Ltd., has started a £1¼ million 5-year expansion plan. Work on the first stage of construction of a 350,000-sq.-ft factory at Tower Hill, Farnborough, Hants, has already begun. The company's wide range of products include flexible analogue computers and simulators for reactor design studies.

British Thomson-Houston Co., Ltd., have presented equipment valued at £9,400 to Queen's University, Belfast.

Wakefield-Dick Industrial Oils, Ltd., have opened a new showroom at Grosvenor Street, London, W.1, featuring examples of the company's range of lubrication equipment.

Elliott-Automation, Ltd., have purchased the entire share capital of **Rotameter Manufacturing Co., Ltd.**

Southern Areas Electric Corporation, Ltd., have acquired the whole share capital of Designs and Installations, Ltd. The company has a factory at Guildford as well as a contract design and drawing office at 28/30 Great Peter Street, London, S.W.1. Designs and Installations are currently studying handling problems in conjunction with the insertion, extraction and examination of control rods.

British Insulated Callender's Cables, Ltd., announce the opening of a new depot at 511 Roumelia Lane, Boscombe, Hants. (Telephone: Boscombe 36233.) Mr. A. J. Pearson is in charge.

C. C. Wakefield and Co., Ltd., are to acquire the entire share capital of Fletcher Miller, Ltd., Alma Mills, Hyde, Cheshire.

1958 Exhibitions

BRUSSELS

Universal and International Exhibition, April 17-October 19. General inquiries: Office of the U.K. Commissioner General, Universal and International Exhibition, Brussels 1958, 83 Baker Street, London, W.1. Space bookings: British Overseas Fairs, Ltd., 21 Tothill Street, London, S.W.1.

1958 British Electrical Conference, Brussels, May 16 and 17. Sam Black, B.E.A.M.A., 36 Kingsway, London, W.C.2.

CHICAGO

Nuclear Congress and Atomfair, 1958. March 17-21, International Amphitheatre.

GENEVA

Second Atomic Energy Exhibition, September 1-14. Palais des Expositions, Genevé. Apply, M. Gabriel Jacques-Dolcroze, Le Secretariat Permanent de l'Automobile, 1 Place du Lac, Genevé, Suisse.

LONDON

Physical Society Exhibition of Scientific Instruments and Apparatus, March 24-27. Old and New Royal Horticultural Society Halls, Westminster, London, S.W.1. Physical Society, 1 Lowther Gardens, Prince Consort Road, London, S.W.7.

Electrical Engineers' Exhibition, March 25-29. Earls Court. Mr. P. A. Thorogood, M.A.S.E.E., 6 Museum Street, London, W.C.1. (Tel., Museum 3450.)

Instruments, Electronics and Automation Exhibition, April 16-25. Olympia, Industrial Exhibitions, Ltd., 9 Argyll Street, London, W.1. (Tel., Gerrard 1622.)

Electronic Computer Exhibition and Symposium, November 28-December 4. Olympia. Mr. J. F. Richardson, Radio Communication and Electronic Engineering Association, 11 Green Street, London, W.1. (Tel., Mayfair 7874.)

MELBOURNE

Australian Industries Fair, February 27-March 22. Exhibition Building. Victoria Chamber of Manufactures, 312 Flinders Street, Melbourne, C.1.

Victorian State Fair, July 21-August 2. Exhibition Buildings. Industrial Public Relations Service of Australia, 82 W. Toorak Road, South Yarra.

MONTREAL

International Trade Fair, May 30-June 8. Show Mart. Montreal International Trade Fair, Ltd., 1600 Berri Street, Suites 227-228, Montreal.

NEW YORK

Second United States World Trade Fair, May 7-17. At New York Coliseum. Apply, Mr. A. P. Wales, British and Commonwealth Office, 36-38 Southampton Street, London, W.C.2. (Tel., Temple Bar 8947.)

OSAKA

Japan International Trade Fair, April 12-27. Apply, Secretary-General, Japan International Trade Fair Commission, Honmachibashi Higashi-Ku Osaka, Japan.

PHILADELPHIA

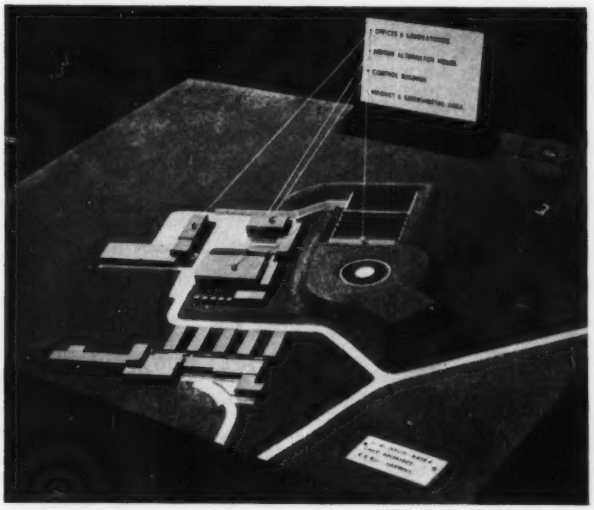
Thirteenth Annual Instrument Automation Conference and Exhibit, September 15-19. Apply, Mr. F. J. Tabery, Instrument Society of America, 3443 South Hill Street, Los Angeles, 17, California.

ROME

Fifth International Congress and Exhibition on Electronics and Nuclear Energy, May 10-25. Rassegna Internazionale Elecronica e Nucleare, Via della Scrofa, 14, Rome.

SYDNEY

Symposium on the Peaceful Uses of Atomic Energy, June 2-6, 1958. The Symposium General Secretary, A.A.E.C. Research Establishment, Private Mail Bag, Sutherland, New South Wales, Australia.



Model of Rutherford high-energy laboratory which is to be erected adjacent to A.E.R.E., Harwell.

Meetings

January 14.—New Developments in Inorganic Ion Exchangers, by J. M. Hutcheon and Dr. C. B. Amphlett. (Society of Chemical Industry, Chemical Engineering Group, 14 Belgrave Square, London, S.W.1, at 5.30 p.m.)

January 15.—Three-day Conference on Nuclear Fuel Cycles. (Institute of Physics, 47 Belgrave Square, London, W.1.) Meeting will be held at The Institution of Civil Engineers, Great George Street, Westminster, London, S.W.1.

January 21.—Symposium on Nuclear Energy. (British Nuclear Energy Conference, The Hoare Memorial Hall, Church House, London, S.W.1, all day.)

January 21.—"Production of Boron 10 by Distillation of Boron Trifluoride," by P. Netley. (Institution of Chemical Engineers, North Western Branch, Blossoms Hotel, Chester, at 7 p.m.)

January 22.—"Heat Transfer Analogues," by N. L. Franklin, G. T. Matthews and J. E. Cook. (Institution of Chemical Engineers, North Western Branch, Chemistry Dept., Lecture Theatre, University of Leeds, at 7 p.m.)

Processes and Equipment

Testing Reactor-Grade Materials

New research equipment designed to provide preliminary creep and stress-rupture data on metals and alloys in gaseous atmospheres at high temperatures and pressures has recently been installed in the materials research laboratory of the G.E.C. Atomic Energy Division at Erith, Kent.

Twelve creep-test units have already done valuable basic work in investigating the properties of magnesium alloys widely employed for fuel element cans, in carbon dioxide atmospheres.

In this new equipment, the specimen, the whole of the stressing apparatus and the associated extensometer are enclosed in a vertical cylindrical pressure vessel. This, in turn, is enveloped along part of its length by an electric furnace.

The body of the pressure vessel, which is of stainless steel $\frac{3}{16}$ in. thick, is approximately 5 ft long and has an internal diameter of 4 in. The upper end of the support rod, from which the specimen is suspended, is welded to the centre of the pressure vessel top plate, while its lower end has a pivoted coupling, with a similar coupling on the top of the pull-rod. Alternative couplings are available so that specimens of either rectangular or circular cross-section can be used. Gas is admitted to the pressure vessel through a tube of $\frac{1}{4}$ in. internal diameter passing downwards through the top plate and a refractory cement plug. A gas outlet tube, of the same diameter, is welded into the side of the vessel below the operating section.

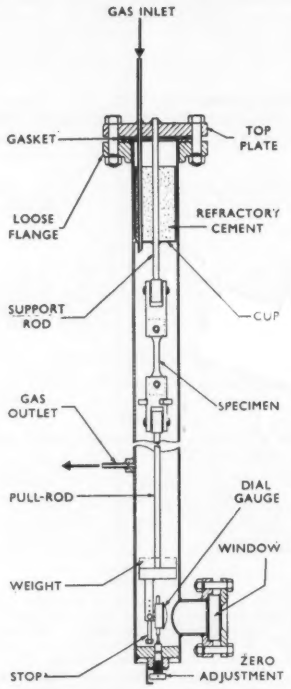
The 4 kW electric furnace, built in two sections, can be split by unbolting two vertical clamping plates, thus allowing the pressure vessel to be removed.

During normal operation, two chromel alumel thermocouples are employed. One is mounted directly on the specimen and is usually connected to a recording instrument. The second is adjacent to the furnace winding and is connected to an Electroflo temperature controller housed in a louvre-ventilated casing built into one of the two terminal chambers. With this arrangement, extremely sensitive regulation of specimen temperature has been achieved.

When the stressing apparatus, with the test specimen mounted in position, has been lowered into the pressure vessel, the top plate is bolted down. The vessel is then thoroughly flushed with the gas being used as the test atmosphere before being brought up to pressure. The supply to the furnace is adjusted, by means of a Variac, to raise the temperature of the specimen rapidly to the required value, and it is then maintained at this level, to a fine degree of accuracy, by the temperature controller.

When stable conditions have been established, extensometer readings are taken at suitable intervals, the results being plotted as percentage creep against time. The total duration of the test varies according to the particular requirements, but is normally between 150 and 1,500 hours.

(General Electric Co., Ltd., Magnet House, Kingsway, London, W.C.2.)



Section through the new creep-testing equipment developed by the General Electric Co., Ltd.

P.T.F.E. Coatings

At their new factory in Tottenham, Siemens Edison Swan, Ltd., are now equipped to coat with P.T.F.E. dispersion articles of all sizes. Newly installed plant includes sintering ovens capable of accepting extremely large components. Conveyor ovens will handle large quantities of small parts. The process results in a completely inert and non-stick surface with an almost zero coefficient of friction.

(Siemens Edison Swan, Ltd., 155 Charing Cross Road, London, W.C.2.)

Thermocouple Wire

A new type of thermocouple wire now being marketed by Philips Electrical, Ltd., has been developed for measuring a wide range of temperatures under extreme conditions. Four different types of wire are available for temperatures ranging from −200°C up to +1,000°C with ceramic-packed single or double core in metal sheathing. Diameters vary between 0.5 mm and 1 mm. The wire can be bent to a curve having only five times the wire diameter and into any configuration without risk of earthing or shorting the cores. It has extremely low heat capacitance at the hot junction and, therefore, a high response sensitivity. Suitable for high-pressure working conditions, it requires no additional insulation, is simple to install and is ideal for multi-point measurement where space is limited.

(Philips Electrical, Ltd., Century House, Shaftesbury Avenue, London, W.C.2.)

High-quality Welding

The KB375 electrically driven welding generator developed by Welding Supplies, Ltd., is now being extensively used at Berkeley nuclear power station. Maximum output of the unit is 375 A with an open circuit voltage of 50 to 100 V. There are four overlapping current ranges with stepless adjustment in each range. A remote-control regulator facilitates welds in difficult positions. Designed for operation at 2,950 r.p.m., the KB375 has an excellent current recovery with outstanding welding characteristics. The unit is extremely portable, being mounted on two pneumatics.

(Welding Supplies, Ltd., Beechings Way, Gillingham, Kent.)

The KB375 welding generator is compact and highly mobile, making it ideal for site use.

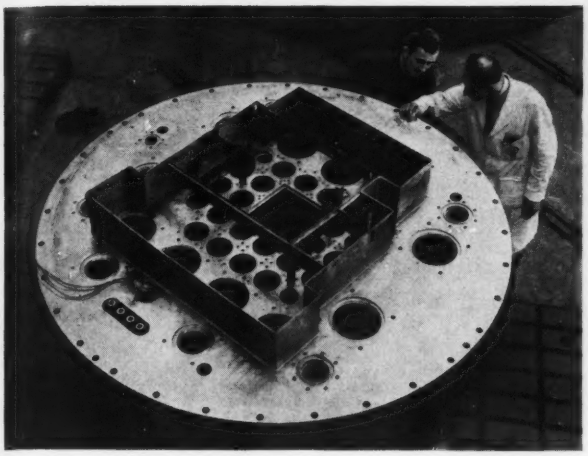
Geiger Counter Tube

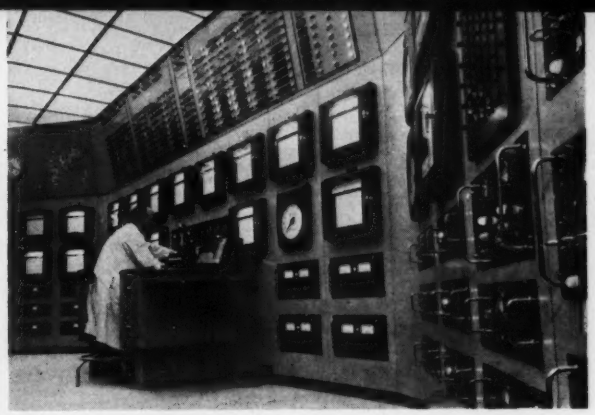
A new Geiger counter tube, type GM4LB, with an extremely low rate of count in the absence of the test specimen has been developed by G.E.C. for the measurement of very minute amounts of radioactivity.

The GM4LB has a thin duralumin window of 1 in. diameter to admit particles from the specimen. The length of the anode wire has been kept to a minimum to reduce the response to any extraneous radiation and the materials used in the construction have been specially selected as free from radioactive contaminants such as potassium and lead which might contribute to the background count.

In order to obtain the minimum background response, the tube must be operated in a heavily-shielded enclosure and surrounded by a ring of gamma counters in an anti-coincidence. Background responses as low as 0.4 counts per minute have been obtained with this network, enabling specimens with an extremely low activity to be measured.

(General Electric Co., Ltd., Magnet House, Kingsway, London, W.C.2.)





(Above) The complete nuclear instrumentation and control circuitry for PLUTO, the new research reactor at Harwell, was designed, installed and commissioned by Ekco Electronics Ltd. This view of the control room shows the central control desk, flanked by the main instrument panels.

(Left) Stainless-steel closure shield for aluminium tank containing the materials testing reactor at Dounreay. Radiation from the reactor core is absorbed by cadmium, lead and iron Shot concrete inside the shield which has a total weight of 21 tons. The fuel element and control rod tubes through the shield were machined to very close tolerances, by Ashmore, Benson, Pease and Co., of Stockton-on-Tees, for Head Wrightson Processes Ltd.

Sub-miniature Trigger Tube

An inexpensive sub-miniature trigger tube for computer applications, is announced by Ericsson Telephones, Ltd. The tube size is only 0.39 in. diameter by 1.32 in. long.

The electrical tolerances of the GTR.120W are slightly wider than those normally encountered in cold cathode tubes, but this is off-set by the tube's long life, reliable operation and very low cost. The anode hold-off voltage is +310 V, and the trigger striking voltage +170 V. Operating current limits are 3-9 mA, and at 4.5 mA the anode cathode voltage lies between 95 and 140 V.

(Ericsson Telephones, Ltd., Beeston, Nottingham.)

Moulded PVC Fans

The Sturtevant Engineering Co., Ltd., have recently announced that in conjunction with Acalor (1948), Ltd., they have produced a range of moulded PVC fans based on their original "Monogram" series. These fans, designed for exhausting corrosive fumes, have moulded casings and fully moulded PVC impeller, thus permitting higher operating speeds and efficiencies than can be obtained with fabricated fans. Further details are available from the addresses given below.

(Acalor (1948), Ltd., Kelvin Way, Crawley, Sussex.) (The Sturtevant Engineering Co., Ltd., Southern House, Cannon Street, London, E.C.4.)

Detecting Laminations

A method of examining cold rolled sheet steel for flaws, has been devised by the British Iron and Steel Research Association (BISRA). The principle of operation is the application of a small electric current through the sheet, the potential difference being measured with a millivoltmeter. The presence of any discontinuity in the path of the current causes the latter to flow round the obstacle instead of in a direct path between the two contact points and the resulting change in potential is registered on the millivoltmeter.

The instrument, known as the BISRA Lamination Detector, consists of two pairs of contacts mounted on duralumin tongs with a thin insulating strip between the current bearing and the potential measuring points. The millivoltmeter dial is mounted on the tongs so that changes in potential are readily visible. The contact points are rounded to prevent the sheet being scratched.

Laminations of a width of $\frac{1}{4}$ in. and above can be reliably detected on cold rolled sheet and narrower ones will frequently register. Laminations on hot rolled sheet, however, cannot always be detected by this method.

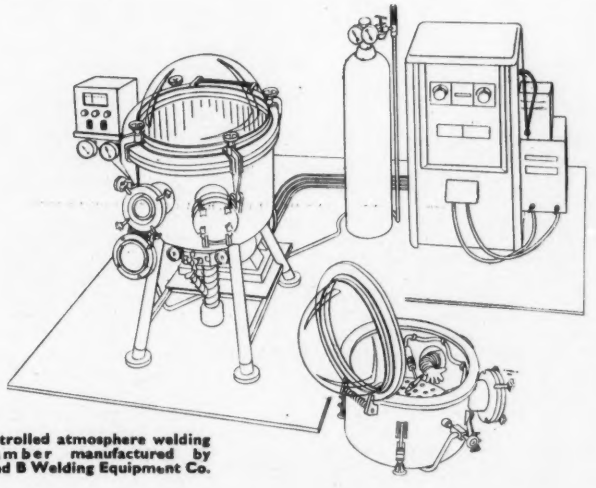
(Ultrasonoscope Co. (London) Ltd., Sudbourne Road, London, S.W.2.)

New Welding Chamber

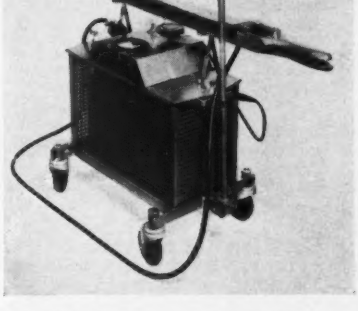
A controlled atmosphere welding chamber has been introduced by L and B Welding Equipment Company of California. Developed from pressure welding chambers built for U.S.A.E.C., the new unit has a Plexiglas dome which offers maximum visibility for welding such metals as zirconium, titanium, Zircaloy-2, and other materials requiring controlled atmospheres. The chamber is also useful for metallurgical research and other activities requiring controlled pressure of inert gas.

The chamber comprises a 24-in.-diameter upright chamber with a bubble-type dome made from materials with low outgassing characteristics. The dome is spring loaded for production welding. By placing valving and pumping apparatus underneath the chamber, total floor space is held to 2½ x 3 ft. Maximum vacuum is 10^{-4} mm Hg reached in approximately 15 minutes with a guaranteed leak rate of 15 microns per hour or less.

(L and B Welding Equipment Company, 2424 Sixth Street, Berkeley 2, California.)



Controlled atmosphere welding chamber manufactured by L and B Welding Equipment Co.



This unit has been developed by the British Iron and Steel Research Association for detecting laminations in cold rolled sheet.

Patents Reviewed

These abstracts have been made from British Patent Specifications, complete copies of which can be obtained from the Patent Office, 25 Southampton Street, London, W.C.2, at 3s. 6d. each (including postage).

B.P. 780,021. Use of emulsified oils for the concentration of uranium ores by froth flotation. P. K. Hosking. To: Minister of Mines for the State of South Australia.

The recovery of uranium minerals by gravity methods has proved very inefficient for low-grade ores. By treating the ore to a state of fineness wherein the mineral particles are freed from the gangue material. Then, first forming an aqueous pulp (having added the required reagents before, during or after the subdividing process) and subjecting the mixture to agitation and aeration in a froth flotation cell, a froth rich in uranium minerals is obtained. The reagents comprise an insoluble and unsaponifiable hydrocarbon oil (e.g. fuel oil) emulsified with an anionic water soluble emulsifying agent (e.g. sulphonated castor oil), and stabilized with an oil soluble stabilizing agent (cresylic acid).

B.P. 780,219. Nuclear reactor provided with a neutron flux measurement device. Commissariat à l'Energie Atomique (France).

In order to measure low levels of neutron flux (reactor out of operation) as well as high levels of neutron flux (normal working) a fixed shield is arranged between the active part of the reactor (within the shielding envelope) and the measurement device. This shield is made of a material having a high mass absorption coefficient for gamma rays, but a small absorption cross section for neutrons, and practically no secondary gamma radiation. Such a material is preferably bismuth. A second retractable shield may be interposed having a large absorption cross section for neutrons.

B.P. 780,283. Ionization chambers. To: Commissariat à l'Energie Atomique (France).

Leakage resistance between electrodes is reduced when the electrodes are arranged one inside the other, and a voltage source (dry battery) is disposed within the chamber; one terminal being connected to the inner electrode, the other to a conductor passing through the wall of the chamber. The external circuit is formed between this conductor and the outer electrode.

B.P. 780,420. Pressure welding of titanium or zirconium or an alloy based on such metal. G. A. Geach, J. E. Hughes. To: Associated Electrical Industries Ltd.

It has been discovered that titanium and certain titanium-based alloys can be united to titanium or certain titanium-based alloys by application of pressure without heating to fusion point. Preliminary tests have also shown that a similar action is possible with zirconium. For joining titanium or zirconium or their alloys and a metal such as copper, iron, aluminium, nickel or their alloys the same method can be used, i.e. pressing continuous clean surfaces together with sufficient force (100 ton/in.^{2}) to produce a certain reduction in thickness resulting in welding the metals together without heat. Aluminium must be reduced to about 35% of its original thickness, copper and lead to about 20%, iron to about 10%, other metals to between 5% and 10%. For titanium and zirconium the figure is about 30%.

B.P. 780,471. Extraction or recovery of uranium and other metals. L. Tavener, D. Millin.

The uranium-bearing ore or concentrate is subjected to chlorination, with elementary chlorine in a liquid aqueous medium, to bring the uranium into soluble form. The solution is then treated to precipitate an insoluble uranium compound. The (roasted) material may, e.g., be leached with an acidified hypochlorite solution, which also may yield gold and other metals. The gold may be deposited in powder form by electrolysis. The uranium may be recovered by normal precipitation.

B.P. 780,477. Process for removing hafnium from zirconium-containing material. I. E. Newnham. To: Commonwealth Scientific and Industrial Research Organization.

The zirconium compounds and the associated hafnium compounds are converted into tetrahalides. The zirconium tetrahalide is reduced to one or more lower halides or even to metallic zirconium, while the hafnium tetrahalide remains unchanged. This and any unreduced zirconium tetrahalide is then separated from the zirconium reduction product.

B.P. 780,736. Electronic apparatus. Isotope Developments Ltd., I. S. B. Eppstein.

A pulse generator for producing pulses randomly distributed in time. The mean pulse repetition frequency (p.r.f.) can be stabilized at any desired value over a wide range. A detector of radioactive energy applies pulses to an amplifier producing pulses exceeding a predetermined value. These pulses are then fed to a circuit which produces a control voltage varying with the mean p.r.f. which, in its turn, varies the sensitivity of the detector to maintain the p.r.f. at a more nearly constant value. In one form of the invention, beta particles emitted by a radioactive source (strontium-90) are converted into electrical pulses by means of a fluorescent screen and a photomultiplier tube.

B.P. 780,974. Production of uranium metal. A. E. Williams. To: U.K. Atomic Energy Authority.

Uranium tetrafluoride and magnesium metal are compacted, e.g. compressed into pellets, so as to raise appreciably the bulk density of the charge. The density should be at least 3 g/cc. If the two reactants are rapidly heated to the temperature of initiation of the reaction, a consistent yield of uranium metal may be obtained. Hitherto large-scale production (batches of 100 kg) using magnesium instead of calcium for the reduction of the tetrafluoride has not been satisfactory because of serious variations in respect of efficiency from batch to batch.

B.P. 781,068. Thickness measuring gauges using radioactive material. Ekco Electronics Ltd., W. E. Thompson, L. E. Taylor.

Especially for controlling the thickness of coatings on a moving sheet, e.g. of paper. The sheet passes first uncoated through one gauge, then coated through a second gauge. The output circuits are connected and produce a control current affecting the rate of travel. The radioactive source used in such gauges is subject to decay and contamination and the ionisation chamber is also subject to contamination so that the output from the ionisation chamber falls with time. To maintain a true indication the balance between the outputs has to be adjusted periodically. This is done by a standardization procedure in which both gauges are measuring standard material (air). The output from the ionisation chamber is compared with a standard voltage. First in order to compensate for different contamination, the spacing of source and detector is adjusted. Then to compensate for decay of the source and contamination, the standard voltages, which are derived from potentiometers, are varied by adjusting the potentiometers. The necessary switching operations are preferably automatic and time-controlled (30 min intervals). As a permanent absorber, a polythene cover is used for the ionisation chamber. This can be replaced periodically to reduce the effect of contamination.

B.P. 781,121. Non-destructive method and means for flaw detection. To: U.K. Atomic Energy Authority. (U.S.A.)

An alternating homogeneous magnetic field is established in the article under test, e.g. by arranging the article between a pair of coils, and a probe element aligned adjacent the article until zero output current is induced in the probe. The entire surface of the article is then scanned with the probe, e.g. by turning the article between the coils and moving it past the probe, or by moving the probe unit along the article. Any output current indicates size and location of flaws (or voids between layers of Bundy tubing).

B.P. 781,224. Combined mixing and settling apparatus for liquids. To: U.K. Atomic Energy Authority. (U.S.A.)

Refers to a multi-stage arrangement of mixer-settlers for handling two liquids of which one is of a relatively high density, such as an aqueous solution of a solvent-extractible metal nitrate (cerium nitrate) containing a salting-out agent (nitric acid); while the other is of low density, such as a water-immiscible organic solvent (tributyl phosphate). The two liquids are to be repeatedly mixed and separated from one another, and the organic solvent is to extract metal values from the aqueous solution. The structural arrangement permits interface control dependent upon the difference in height of overflow and top of weir tube. By adjustment of the weir tube the control of the interface between liquids, even of small density difference, is easily accomplished. This is important, as the densities of the liquids vary from one settling chamber to the other; depending on how completely they are separated, and on the extent to which the metal values have been transferred from the aqueous solution to the organic solvent in these chambers.